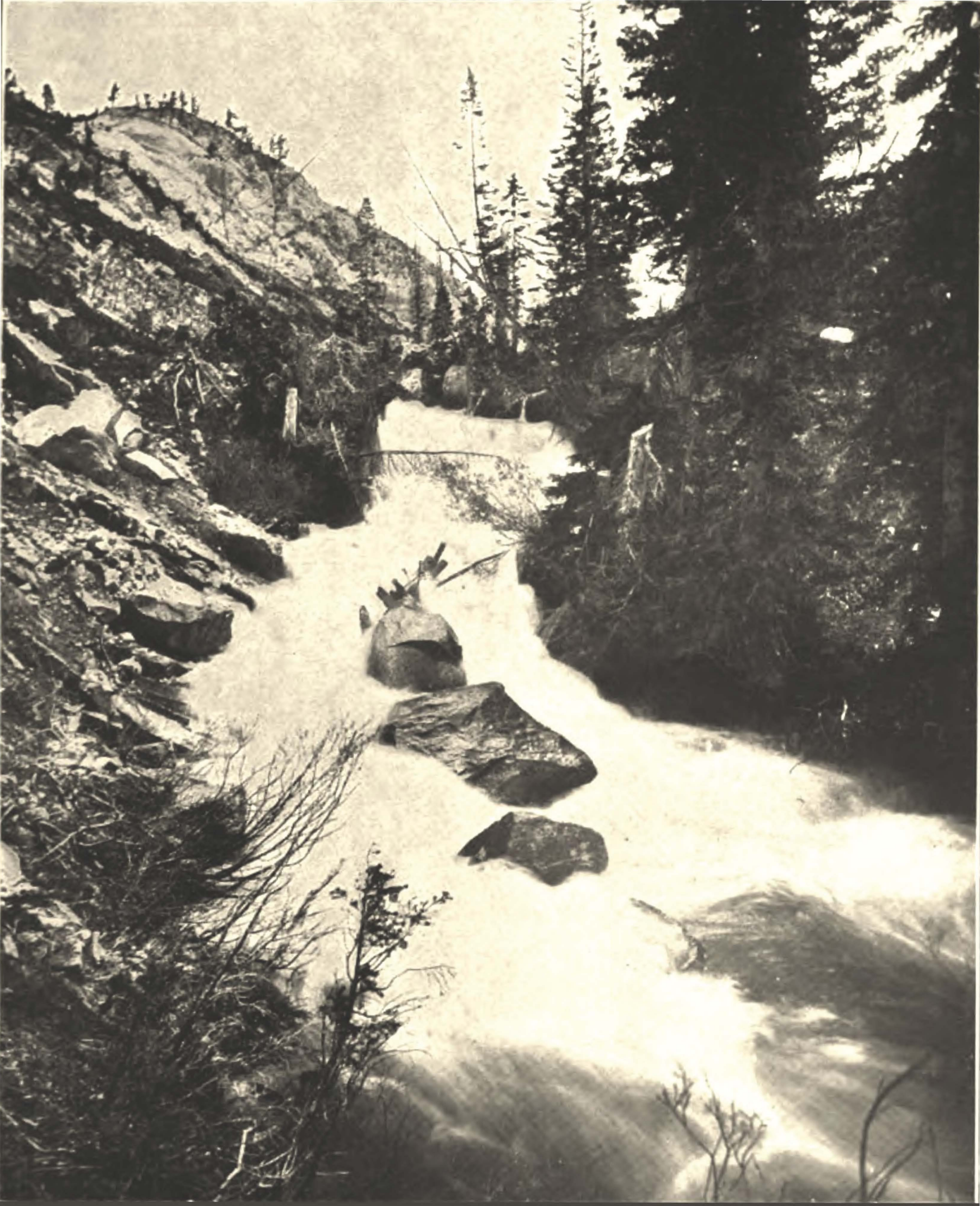

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

UNDERGROUND WATER

IN THE

VALLEYS OF UTAH LAKE AND JORDAN RIVER, UTAH

BY

G. B. RICHARDSON

WASHINGTON
GOVERNMENT PRINTING OFFICE
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The present mountains are the eastern part of a greater mass of rocks, the Wasatch Range having been raised by faulting several thousand feet higher than the western part of this mass, which now lies buried beneath the valley deposits. This great fault is the dominant structural feature of the region. The range rises abruptly 7,000 feet above the wide lowland at its base, where the streams, which in their mountain courses occupy deep-cut narrow gorges, flow in wide valleys. The fault cuts across the range regardless of the structure of the rocks, and the truncated mountain bases abut against the plain in marked alignment.

Beginning at the north and proceeding southward the following features may be noted: The spur that juts out from the Wasatch Mountains north of Salt Lake City marks the southern boundary of a series of pre-Cambrian rocks that constitute the crest and western flanks of the mountains to the northwest, almost as far as Ogden. These rocks for the most part consist of gneisses and mica-schists, considered to be of sedimentary origin, with which are associated quartzites, slates, and some igneous rocks. In general the strike is N. 20° W., and the prevailing dip is westerly at angles ranging from 15° to 20°. A great thickness of coarse Tertiary conglomerate lies high up on the northeastern flanks of the range, but at the southeastern end of the crystalline area Paleozoic sediments abut against the older series and dip southeastward.

An outlying mass of nearly horizontal coarse Tertiary conglomerate, composed chiefly of pebbles of limestone and quartzite, caps the spur of the mountains north of Salt Lake City and conceals the older sediments except along the western base of the spur, where the Wasatch limestone outcrops. A small isolated body of volcanic rock outcrops in the midst of the Tertiary area and is bisected by City Creek. The headwaters and upper course of City Creek lie in Paleozoic rocks, chiefly in the Weber quartzite and Wasatch limestone, which dip southeastward at angles varying from 30° to 65°. Across the divide a large area of flat-lying Tertiary rocks cap the disturbed Paleozoic series.

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Between City and Big Cottonwood creeks the summit and western face of the mountains are occupied by an immense syncline striking nearly east and west. Its western end is terminated by the Wasatch fault, which cuts directly across the fold and exposes the structure so that it can be plainly seen from Jordan Valley. The axis of the syncline coincides approximately with the course of Emigration Creek. In detail, however, the structure is complicated by a number of relatively minor disturbances.

East of Salt Lake City upper Carboniferous and Permian strata, consisting chiefly of limestone, outcrop between City and Red Butte creeks, and dip southward, forming the northern limb of the syncline. Red Butte Canyon lies in Permo-Carboniferous rocks, but near the mouth of the canyon "Red Beds" outcrop and continue along its southern divide. The "Red Beds" consist chiefly of red shales and sandstones, aggregating over 1,000 feet in thickness and are overlain by thin-bedded, argillaceous limestones and shales of Jurassic age. These rocks occupy the center of the syncline, and outcrop in the valley of Emigration Creek.

South of Emigration Creek the summit and western face of the Wasatch Mountains are occupied by the southern limb of the syncline as far as Big Cottonwood Creek, and the succession of rocks mentioned above is repeated in reverse order. The dips generally are northward, but there are minor folds and faults.

Parleys Creek rises in the Cretaceous sandstone and conglomerate that, east of the main Wasatch ridge, lie unconformably upon the older rocks. After traversing this area it crosses a narrow belt of Red Beds and, for 5 miles above the mouth of its canyon, flows over calcareous and argillaceous Permo-Carboniferous rocks. Carboniferous strata occupy the divide between Parleys and Mill creeks, the latter of which flows for the greater part of its length in the Weber quartzites.

Between Mill and Big Cottonwood creeks the lower Paleozoic rocks outcrop. Big Cottonwood Creek exposes for 6 miles above the mouth of its canyon a great thickness of Cambrian strata, consisting of siliceous slates and quartzites; in the upper part of its course this creek crosses the Weber quartzite and Wasatch limestone, and heads in the crystalline rocks of Clayton Peak. Little is known of the occurrence of Silurian and Devonian sediments in this area. Their presence was recorded by the early surveys, but the little detailed work that has been done shows that in a few localities at least these systems do not appear to be represented by sediments.

Little Cottonwood Creek for about 8 miles from the mouth of its canyon flows through a crystalline area, and heads in Paleozoic strata and igneous rocks at the foot of Clayton Peak. The western base of the mountains extending north and south of Little Cottonwood Creek is occupied by a belt of schistose rocks about 10 miles long and averaging perhaps 1 mile in width. These rocks are of pre-Cambrian age and are over a thousand feet thick. They consist largely of quartzite, but include also slates and mica-schists, having an apparent steep western dip. Up Little Cottonwood Creek, beyond the pre-Cambrian area, lies a large body of granitic rocks, which forms high peaks north and south of the creek, and through which the stream flows for the greater part of its course. The Paleozoic sediments arch around this granitic area, dipping away from it to the north, east, and south, forming a dome the western part of which has been cut off by the Wasatch fault.

The age of the "Little Cottonwood granite" has been the subject of some discussion. It clearly cuts the pre-Cambrian rocks at the mouth of the canyon, but its relation to the Cambrian was not definitely determined by the early surveys, though the granite was thought to be of pre-Cambrian age. Recently, however, it has been shown [a] that the "granite" is an intrusive mass that cuts the Cambrian quartzite, though the age of the intrusion is not yet known.

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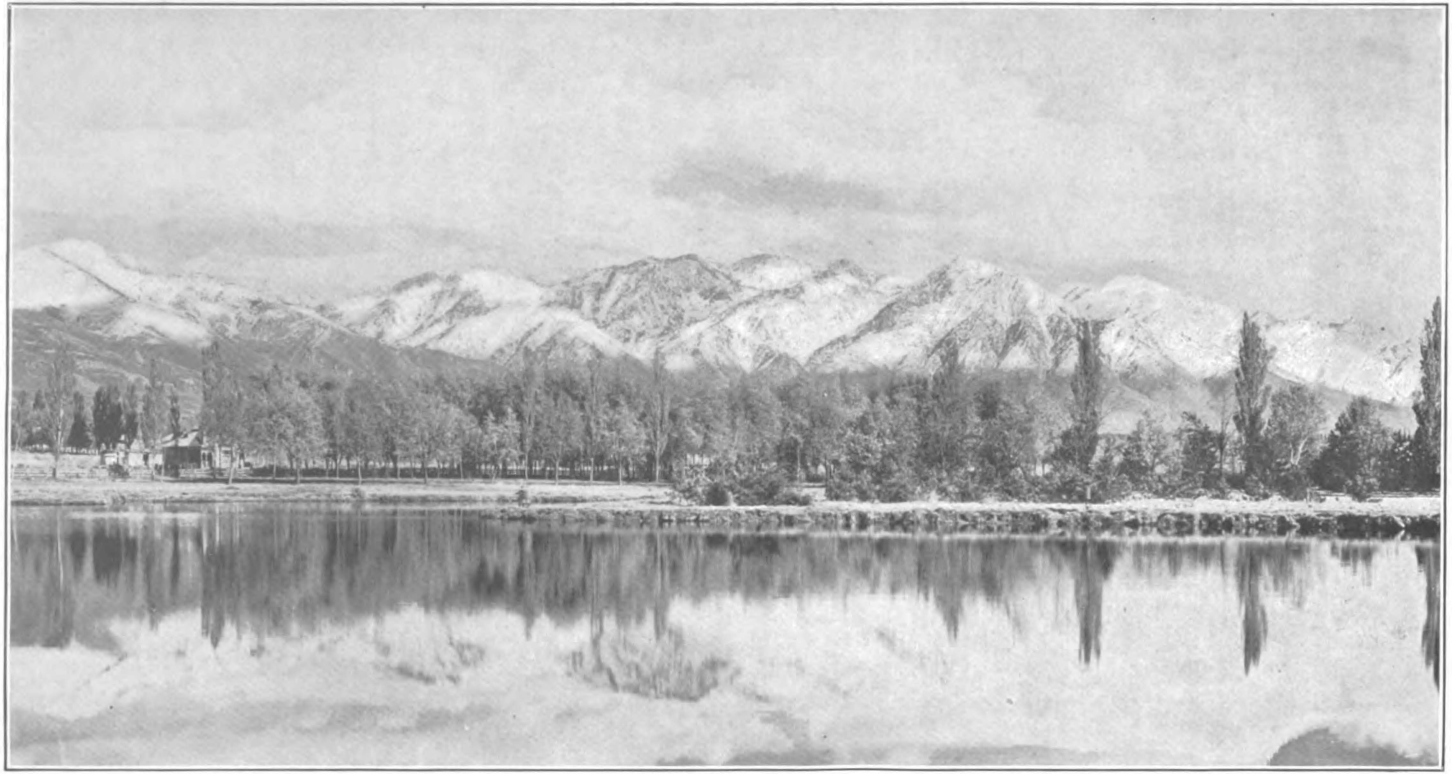
[a] Emmons, S. F., Am. Jour. Sci., 4th ser., vol. 16, August, 1903, p. 139.



WASATCH MOUNTAINS FROM LIBERTY PARK, SALT LAKE CITY.

Lake in foreground is supplied by artesian wells.

UNDERGROUND WATER IN THE VALLEYS OF UTAH LAKE AND JORDAN RIVER, UTAH.

By G. B. Richardson.

INTRODUCTION.

The valleys of Utah Lake and Jordan River are situated in north-central Utah, in the extreme eastern part of the Great Basin. The lofty Wasatch Range (Pl. I), the westernmost of the Rocky Mountain system, limits the valleys on the east, and relatively low basin ranges—the Oquirrh, Lake, and East Tintic mountains—determine them on the west. The valleys trend north and south, and are almost separated by the low east-west Traverse Range, the slopes of which constitute a dam for Utah Lake, which drains through Jordan River to Great Salt Lake.

The area under consideration is the most populous and flourishing part of the State. Salt Lake City and Provo, the first and third cities in the State, and many other thriving settlements are there located. At Bingham Junction and Murray a number of smelters treat the ores from near-by mines, but agriculture is the main industry. Water for irrigation is supplied by mountain streams, and intensive farming is successfully pursued. The practice of irrigation was begun by the Mormon pioneers in 1847, and has been discussed in several publications; little attention, however, has been given to the underground water resources, and, so far as the writer is aware, they have not before been described. The present paper outlines conditions of occurrence of the subterranean waters and describes their development in the valleys of Utah Lake and Jordan River.

TOPOGRAPHY AND DRAINAGE.

The drainage area of Utah Lake and Jordan River is approximately 3,300 square miles, of which 2,600 are tributary to Utah Lake and 700 to the Jordan north of the Traverse Mountains (Pl. II). About 2,000 square miles of the watershed are in the Wasatch Mountains, while the valleys themselves cover a little less than 1,000 square miles. Utah Lake Valley is about 38 miles long, averages 15 miles in width, and occupies about 560 square miles, including Utah Lake. Jordan Valley is approximately 28 miles long, 15 miles wide, and comprises 420 square miles. These valleys in late geologic time were occupied by Lake Bonneville, the Pleistocene predecessor of Great Salt Lake, and to that fact is due their characteristic topography. Almost flat unconsolidated lake sediments underlie the broad valleys, the borders of which are marked by a unique series of terraces that characterize the shore lines of the old lake. Descriptive details of these features will be given in the sections devoted to geology and to the occurrence of underground water.

The range in elevation is considerable. The present level of Great Salt Lake is approximately 4,210 feet above the sea, and that of Utah Lake is about 4,480 feet. From these lowest elevations the two valleys rise to their outer borders, which may conveniently be taken as the highest level occupied by Lake Bonneville, at approximately the 5,200-foot contour, above which the Wasatch Range towers up to 12,000 feet. The mountains on the west are narrow north-south ranges that rise abruptly from broad valleys. The

Oquirrh Mountains, west of Jordan River, are 30 miles long, 5 to 10 miles wide, and their summits rise to elevations of about 10,000 feet. The Lake Mountains, west of Utah Lake, are about 15 miles long, 5 miles wide, and 3,000 feet above the lake. They are connected by low hills with the Oquirrh Mountains on the north and with the East Tintic Mountains on the south. The East Tintic Mountains border Utah Lake Valley on the southwest, rising above it about 3,000 feet. A spur from these mountains extends northeastward, constituting the southern border of Utah Lake Valley, and almost unites with the Wasatch Range. The steep western face of the Wasatch Mountains rises about 7,000 feet abruptly above the broad valley and constitutes the dominant topographic feature of the region. To the east the range slopes away gradually in a series of broad ridges and narrow valleys to the mountainous plateau region. The western scarp is deeply dissected by canyons, through which the entire Wasatch drainage flows to Great Salt Lake, the chief streams being Bear, Weber, and Jordan rivers.

Utah Lake is a body of shallow water about 21 miles long and 7 miles wide (Pl. III, *A*), covering a maximum area of 93,000 acres. Its depth over much of its extent is only 8 feet or less, and the maximum depth in the main body of the lake is about 13 feet. In its northwestern part, however, recent soundings have revealed the presence of several deep holes, due to springs (p. 49). The shore line of the lake is subject to considerable variation, owing to the changing relations of evaporation, precipitation, and inflow, and the margins are characteristically swampy. Two large, shallow bays extend eastward and southward from the main body of the lake, one south of Provo and the other north of Goshen. West of the lake the Pelican Hills approach close to the shore, and the region is barren, but on the north, east, and south the land rises gently toward the base of the mountains and is dotted with flourishing settlements which are supported by irrigation.

The principal streams tributary to Utah Lake, beginning at the north and proceeding southward, are: Dry, American Fork, Battle, and Grove creeks, Provo River, Hobble Creek, Spanish Fork, and Peteeneet, Santaquin, and Currant creeks. Of these, Provo River is the largest, being approximately 70 miles long and having a drainage area of 640 square miles. It rises in the Uinta Mountains near the sources of Weber, Bear, and Du Chesne rivers, flows westward and southward through Kamas and Provo valleys, and passes through the Wasatch Mountains in a deep canyon. On entering Utah Lake Valley Provo River flows almost due south for 5 miles, skirting the great Provo delta, and thence westward, entering Utah Lake about 3 miles west of Provo.

Spanish Fork has a watershed about equal to that of Provo River, but not so great a discharge. It rises near Soldier Summit, and, after receiving two main tributaries, North and Thistle creeks, flows in a canyon through the main ridge of the Wasatch Mountains and enters Utah Lake Valley at the head of the large embayment that extends between Payson and Springville.

Salt Creek rises in the southern Wasatch Mountains, on the eastern slope of Mount Nebo, and, after crossing the border of the plateau region, emerges into the broad valley at the southwestern base of the Wasatch Mountains where, in summer, it ceases to flow at the surface. The drainage way continues, in a narrow canyon, through Long Ridge which partially connects the East Tintic and the Wasatch mountains, and enters the southern end of Utah Lake in Goshen Valley, where the stream, which is fed largely by seepage, is known as Currant Creek.

The other tributaries of Utah Lake are relatively small. The chief ones rise in the Wasatch Mountains and occupy canyons in their mountain courses, where they maintain perennial flows. At the mouths of the canyons canals divert the water and distribute it over the valley, so that in the irrigation season practically all of the available supply is thus used and the beds of the streams in Utah Lake Valley are commonly dry; but in the late spring and early summer, during the period of melting snow, large volumes are discharged directly into the lake.

Jordan River heads at the northern end of Utah Lake and flows northward in a meandering course of about 40 miles to Great Salt Lake. For the first 5 miles the river flows slug-

gishly in a broad valley, and in that distance falls only about 10 feet. In the "narrows," however, the river occupies a constricted channel and descends rapidly; in the first mile below the intake of the canals its fall amounts to about 70 feet. Below the "narrows" the valley spreads out and at its greatest width is about 18 miles wide. The country rises gradually toward the adjacent highlands to the base of the terraces that mark the shore lines of Lake Bonneville, whence the ascent is by successive steps. Between Salt Lake City and Great Salt Lake the topography is almost flat, and a number of small lakes of shifting outline occupy local depressions. As the shore of Great Salt Lake is approached there is a faint slope of the surface which becomes increasingly marshy. This area west of Salt Lake City in general is barren and desolate and the surface in many places is white with alkali. On the uplands, away from the lake, alkali is scarce, but the western part of the valley, because of the lack of water, suffers in comparison with the cultivated eastern part, which is supplied by streams from the Wasatch Mountains.

North of the Traverse Mountains the principal tributaries of Jordan River are City, Red Butte, Emigration, Parleys, Mill, Big Cottonwood, Little Cottonwood, Dry Cottonwood, and Willow creeks, all of which issue from the Wasatch. In their mountain courses these creeks generally occupy narrow canyons from which they emerge on the lowlands and flow in broad open valleys to the Jordan. Within the mountains they are all perennial streams, but at the mouths of the canyons their flow is largely diverted by irrigation ditches, so that, in the dryest part of the year, their lower courses are generally dry. They rise in the main crest of the Wasatch and have small watersheds, Big Cottonwood Creek, draining about 48 square miles, being the largest. This stream rises at the base of Clayton Peak, is fed by a number of small lakes, and discharges a considerable quantity of water through a narrow canyon (Pl. IV, *B*).

The vegetation is scanty. The valleys in their natural state are occupied by sagebrush, greasewood, and kindred desert plants, but wherever water is available there is a marked contrast, and the irrigated areas of these valleys rival in productiveness any in the country. Sugar beets are grown in quantity; alfalfa, potatoes, corn, etc., are common crops; and on the bench lands a variety of fruits are successfully cultivated. The mountains on the western border are generally barren; sagebrush and occasional cacti are the chief growths on the slopes, while scrub oak and stunted spruce and pine here and there grow in patches; the summits are usually bare. The Wasatch Mountains are more favored, but they do not support a heavy growth of trees. At the heads of the valleys scattering pine, juniper, mountain mahogany, and quaking aspen locally occur, and cottonwood, birch, and maple are often found near the stream beds. The slopes are commonly covered with underbrush in varying degrees of thickness, sagebrush and scrub oak being prominent.

GEOLOGY.

LITERATURE.

This area has been studied by prominent geologists and has inspired some classic works on American geology. King, Emmons, and Hague of the Fortieth Parallel Survey[a] interpreted the main features of the region, and Gilbert made it famous by his investigation of Lake Bonneville.[b] But although this interesting region lies contiguous to one of the main transcontinental routes and has been visited by many geologists, yet comparatively little detailed work has been done in it. Walcott[c] has studied the Big Cottonwood Cambrian section, G. O. Smith and G. W. Tower[d] have examined the Tintic district, J. E. Spurr[e] has

[a] King, Clarence, Systematic geology: Rept. Geol. Explor. 40th Par., vol. 1, 1872; Hague, Arnold, and Emmons, S. F., Descriptive geology: Ibid., vol. 2, 1877.

[b] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890.

[c] Walcott, C. D., Bull. U. S. Geol. Survey No. 30, 1886, p. 38.

[d] Tower, G. W., and Smith, G. O., Geology and mining industry of the Tintic district, Utah: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 601.

[e] Spurr, J. E., Economic geology of the Mercur mining district, Utah. Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 343.

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Parleys Creek rises in the Cretaceous sandstone and conglomerate that, east of the main Wasatch ridge, lie unconformably upon the older rocks. After traversing this area it crosses a narrow belt of Red Beds and, for 5 miles above the mouth of its canyon, flows over calcareous and argillaceous Permo-Carboniferous rocks. Carboniferous strata occupy the divide between Parleys and Mill creeks, the latter of which flows for the greater part of its length in the Weber quartzites.

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[a] Emmons, S. F., Am. Jour. Sci., 4th ser., vol. 16, August, 1903, p. 139.

Traverse Mountains are largely composed of younger lavas, which conceal the rocks upon which they lie.

In the "narrows" where Jordan River flows through the Traverse Mountains, practically horizontal Pleistocene gravels, which form the great embankment at the point of the mountain, are unconformably underlain near the river level by fine-textured sediments that dip southeastward at an angle of 40°. The lower part of these sediments consists of light calcareous clay and the upper part of fine sand and gravel. No fossils were found, but the marked unconformity and the character of the material suggest that the age of the lower deposits is Tertiary.

East of Utah Lake the great Wasatch fault is impressively shown by the remarkable alignment of the base of the mountains extending from Spanish Fork Canyon to the Traverse Mountains in an approximately straight line, and by the abrupt rise of the mountains above the broad valley. Second and third lines of faulting, lying parallel to the main fault and east of it, are suggested by the topography, which rises steplike, with two intervening treads between the ascents, to the top of the main ridge, and by the unusual thickness of limestone exposed, which apparently requires repetition by faulting for the explanation of its occurrence.

In this part of the range a disturbed belt of rocks with prevailing steep westerly dips occurs along the western base of the mountains, beyond which the strata dip eastward at low angles and the summits of the main ridge are capped by limestone lying almost flat. The streams that cross the mountains, therefore, flow transversely to the strike of the rocks, in marked contrast to the creeks farther north, whose courses lie approximately parallel to the strike.

Excellent sections can be measured along the canyons, but very little detailed work has yet been done. The rocks in general are quartzite and limestone of Carboniferous age, but locally Cambrian sediments also occur. In Rock Creek Canyon, east of Provo, in the lower end of the gorge, the rocks are much disturbed and are complexly folded. Here a considerable thickness of white quartzite outcrops, overlain by a great mass of limestone. In a thin bed near the base of the limestone G. H. Girty obtained a few Cambrian fossils, and about 600 feet above, in massive gray limestone, the beds being apparently conformable, he found Lower Carboniferous fossils.

South of Hobble Creek easterly dips prevail from the base of the mountains as far as Spanish Fork, beyond which the range has been very little studied. It trends southwestward and terminates at Mount Nebo, the main mass of which is composed of steeply west-dipping limestone and subordinate quartzite of upper Carboniferous age. The highland farther south consists of a series of plateaus, which are underlain by low-lying Mesozoic and Tertiary rocks.

The highlands that border the valleys of Jordan River and Utah Lake on the west are for the most part composed of the same rocks that occur in the Wasatch Mountains, but the structural relations are completely hidden by the deep filling of the intervening valleys.

The Oquirrh Range is composed mainly of Carboniferous limestones and quartzites, which, in the southern part of the mountains, are folded into two parallel anticlines with an intervening syncline. The axes of folding are obliquely transverse to the topography, the range extending in a north-south direction while the structural trend is northwestward. The structure of the northern part of the mountains is little known, but the range is probably terminated by a fault. Rocks of Cambrian age are exposed locally by a fault in the vicinity of Mercur, and igneous rocks, both extrusive and intrusive, also occur. The intrusive rocks include both acidic and basic porphyries, which are conspicuous in the vicinity of the mining camps of Bingham and Mercur; the extrusive rocks, largely andesitic, occur principally along the eastern base of the range and in the Traverse Mountains.

The Lake Mountains, or Pelican Hills, west of Utah Lake, are composed of Carboniferous limestones and quartzites which constitute a low synclinal fold, and are separated from the Traverse Mountains by a narrow strip of Pleistocene deposits. A line of hills,

composed chiefly of west-dipping limestone, separate the Lake Mountains from the East Tintic Range—the succeeding highland mass to the south. The northern end of these hills is capped by horizontal basalt with which light pumiceous tuff is associated.

The East Tintic Range, a complex mass of sedimentary and igneous rocks, forms the southwestern border of Utah Lake basin. As in Rock Canyon, the sediments consist of Cambrian quartzite and Carboniferous limestone in juxtaposition, indicating the absence of the Ordovician, Silurian, and Devonian. The main structure of the sedimentary rocks is synclinal, but these constitute a relatively small part of the outcrops, igneous rocks, rhyolite, andesite, monzonite, and basalt occupying most of the region. These are of both extrusive and intrusive origin, and are of Tertiary age. The low spur of the Tintic Mountains known as Long Ridge, which lies south of Goshen and connects with the Wasatch—save for a narrow Pleistocene strip south of Santaquin—consists of andesite in its southern part, while southeast-dipping Carboniferous limestones outcrop in the gorge of Currant Creek.

LATE GEOLOGIC HISTORY.

The above résumé implies for this region a complex geologic history which need not here be discussed. A statement of late geologic events will, however, add to a clearer understanding of the valley deposits in which the underground water is stored.

TERTIARY HISTORY.

After many thousands of feet of sediments had accumulated in Paleozoic and Mesozoic time, during which the general region was occupied by oceanic waters, profound continental uplift occured in early Tertiary time. Since then the ocean has not invaded the interior of the continent and during Tertrary time much of the Cordilleran region is believed to have been occupied by a number of lakes in which a considerable thickness of rocks accumulated. During the Eocene, according to the geologists of the Fortieth Parallel Survey, a great fresh-water lake occupied the Wasatch Mountain area, and toward the close of this epoch the mountains were finally uplifted and the relative depression of the Great Basin originated. The late Tertiary witnessed the formation of several lakes whose positions were determined by different crustal movements, and these lakes persisted with varying relations into the Pleistocene epoch. The end of Tertiary time was marked by further earth movements that divided the Great Basin area into two main depressions, following the bases of the recently uplifted Wasatch Mountains and the Sierra Nevada. In Quaternary time the bordering mountains were occupied by glaciers, and enormous lakes accumulated in the marginal depressions of the Great Basin. The two largest of these have been named after early explorers. Lake Lahontan covered an immense area in western Nevada and Lake Bonneville occupied a considerable part of western Utah and extended into adjacent parts of Nevada and Idaho.

QUATERNARY HISTORY.

The existence of Lake Bonneville is borne witness to by a number and variety of facts, chief of which are the remains of shore lines and shore deposits, and the great thickness of sediments that accumulated in the lake and that now constitute the valley floor. At its greatest extent the water of Lake Bonneville was approximately 1,000 feet above the present surface of Great Salt Lake. This large body of water abutted against the adjacent highlands and the outline of the lake was intricate. Deep bays and jutting promontories marked the shores, and lone mountains, partly submerged, stood out as islands.

The area considered in this report formed part of one of these bays. This—

> was divided by a close stricture into an outer bay and an inner, the outer covering the valley of the Jordan River and the inner spreading over Cedar, Utah, and Goshen valleys and a part of Juab Valley. In the inner bay the Goshen Hills made two islands, and the Pelican Hills constituted one large and several small islands. Small estuaries occupied Emigration and Little Cottonwood canyons, connecting with the outer bay, and the inner bay sent an estuary into Provo Canyon.[a]

[a] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, p. 103.

During the existence of Lake Bonneville sedimentation was practically continuous in its lowest depression, but toward the periphery oscillations of the water level alternately covered the lake deposits and exposed them to subaerial influences. Evidence of the earliest Pleistocene history of the Bonneville region is furnished by alluvial cones that extend nearly to the bottom of the basin. These are composed of detritus derived from the adjacent highlands under subaerial conditions and could not have been accumulated when the level of the lake was high. It is therefore concluded that at this early period in the history of the lake comparatively arid conditions prevailed, for the stage of a lake in a closed basin is determined by the relation of evaporation to water supply. It has also been determined that at this period of the history of the lake it had no outlet and that the time of duration of low water was relatively long.

Next succeeded a period of high water, when yellow clay, locally streaked with sand, was deposited in a large part of the lake. The base of the yellow clay has not been observed and good sections are rare, though an exposure 150 feet thick has been measured. The deposit locally extends to within 120 feet of the highest level attained by Lake Bonneville, but a study of the shore line shows that during the deposition of the yellow clay the water did not rise to the rim of the basin. In the lower part of the basin the yellow clay is unconformably overlain by a deposit of white marl, local streaks of alluvium occurring at the contact. The white marl is composed of a fine calcareous clay consisting of calcium and magnesium carbonates, microscopic siliceous organic remains, and fine clastic débris.

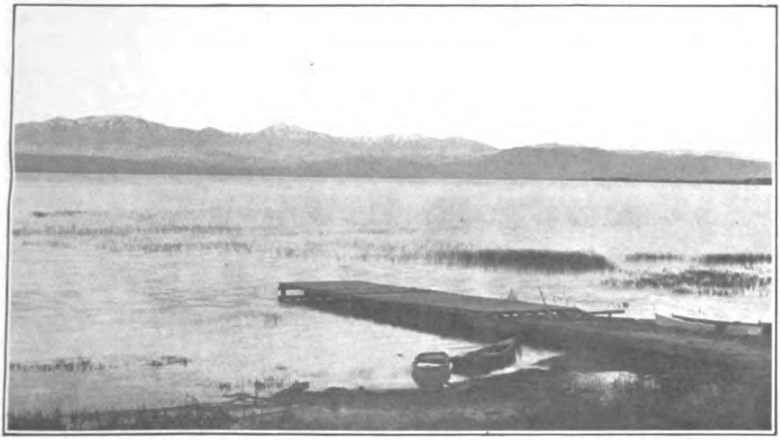
These facts imply (1) that after the deposition of the yellow clay the lake water subsided, (2) that the clay was eroded, and (3) that a second period of high water subsequently ensued when the white marl was deposited. The extent to which the waters subsided is undetermined, but the possibility of complete desiccation is suggested by the difference in character between the yellow clay and white marl. The extent of the second period of high water is determined by the highest shore line traceable along the adjacent mountain flanks. This level is approximately 1,000 feet above Great Salt Lake and is known as the Bonneville shore line. The lake then outflowed through Cache Valley into the Snake River basin.

The Bonneville shore line marks the highest stage of Lake Bonneville and the level of its initial outflow. Beneath this level the drainage channel was cut down by the outflow of the lake to a depth of approximately 375 feet. That the lake maintained its level at the stage of lowest outflow for a relatively long time is attested by the well-developed shore phenomena at the corresponding elevation. This stage determined the Provo shore line, so named from its great development near that town.

The present conditions have been brought about by the recession of the lake's surface, due to the excess of evaporation over inflow, so that now Great Salt, Utah, and Sevier lakes are the sole remnants of the former great body of water. The recession has uncovered the great expanse of lake beds that underlie the intermontane plains and constitute the fertile lands at the base of the Wasatch Mountains, and has also exposed the remarkable shore phenomena that testify to the history of Lake Bonneville, so completely worked out by Gilbert.

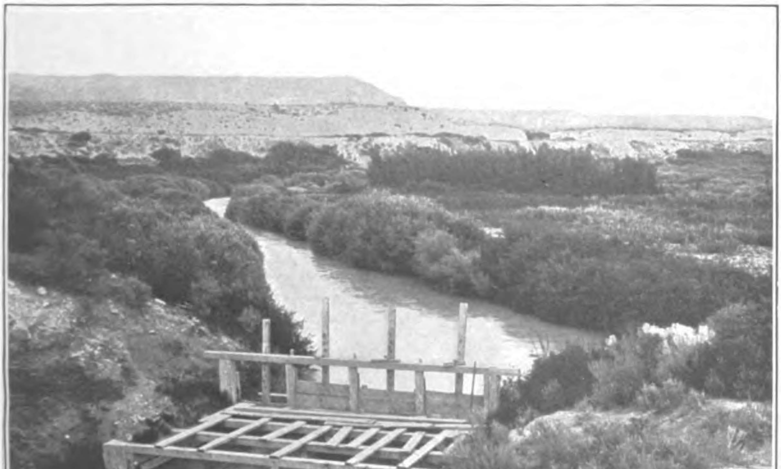
The Bonneville basin is preeminently characterized by its many shore lines (Pl. III, *B*), the highest of which impinges against the mountains and the lowest of which that can be recognized incloses the area covered by the lake sediments. Through a vertical interval of 1,000 feet the story of the rise and fall of this body of water is recorded by the superposition of shore line upon lake sediment and of lake sediment upon shore line. The record is not in all cases perfectly legible, but the main features are unmistakable.

The work of waves is recorded by cliffs and wave-cut terraces, from which the débris was carried along the shore to make benches, bars, spits, and terraces. The streams loaded with the waste of the land areas deposited their burdens in the lake, the coarser detritus being laid down near shore while the finer sand and clay were carried far out before sedimentation occurred. Deltas were formed at the mouths of the larger creeks where so much débris was carried that the shore currents could not distribute it. Since the recession of



A. NORTHERN END OF UTAH LAKE.

Oquirrh Mountains in background.



B. HEAD-GATE OF JORDAN AND SALT LAKE CITY CANAL, LOOKING SOUTH.

Embankment at point of the mountain in background.

the lake from its old shores the streams which formed the deltas have begun their destruction by cutting them in two in their progress toward the shrunken body of water.

The Bonneville is the most conspicuous of all the shore lines, not because of the relative duration of time during which it was formed but because being the topmost of the series, it emphasizes the contrast between the sharply carved subaerial erosion features of the main land and the broad horizontal lines due to the influence of the lake. Study of the levels of bars at this stage shows that the record is complex and that the water surface alternately rose and fell a few feet during the formation of the shore phenomena that mark the general Bonneville level.

Below the Bonneville there are a number of plainly marked shore lines which represent stages in the level of the lake when it was practically constant for relatively long periods. Of these shore lines the Provo is the most remarkable, for it records the longest occupancy of one approximate horizon of any of the stages of the lake. Its embankments are the most massive and its wave-cut terraces are the broadest, notwithstanding the fact that the lake at the Provo stage was considerably smaller than when the surface of the water was 375 feet higher, its area having shrunk from 19,500 to approximately 13,000 square miles. The Provo shore line is characterized particularly by its deltas, which were formed at the mouths of all the larger streams that entered the lake.

The fall from the Bonneville to the Provo level was apparently without interruption and comparatively rapid. But below the Provo stage there are remnants of shore lines and terraces at a number of horizons that record temporary halts of greater or less extent in the gradual shrinkage of the lake. The most conspicuous of these lower shore lines, at an elevation of approximately 750 feet below the Bonneville level, has been named the Stansbury shore line, from its prominent development on Stansbury Island, but the others have not been correlated. As many as ten distinct shore lines can be traced on the west side of Jordan Narrows.

In connection with the different shore lines it is of interest to note that Gilbert has found evidences at a few localities of oscillations of the lake level between the Provo and Bonneville horizons, which appear to record halts in the rise of the lake as it approached its maximum. This is unusual, for most of the observed shore phenomena were formed during the retreat of the lake.

Local deposits of calcareous tufa occur associated with the various shore lines, but are most abundant at the Provo horizon. The tufa appears to have been deposited by precipitation from the lake waters due to aeration of the waves, especially during storms, and consequent loss of carbon dioxide by which the carbonate of lime was held in solution. The tufa occurs as a cement to gravel and as a more concentrated deposit, from a few inches to a few feet in thickness, coating exposed surfaces.

Below the Provo horizon, lake beds consisting of subhorizontal or gently lakeward-sloping sediments are associated with shore deposits until, as the valley bottom is approached, shore markings become indistinct and the lake beds prevail. The deposits of yellow clay and white marl previously mentioned as being widely distributed in the Bonneville basin apparently are not typically developed in the bay of the old lake, which occupied the area under consideration. A number of deep wells have been sunk into the valley deposits and their records indicate the general composition of the sediments (Pl. V). The beds are at least 2,000 feet thick, and consist of gravel, sand, and clay, which constitute the reservoirs in which ground water is stored.

CLIMATE.

Weather observations have been systematically recorded at Salt Lake City for thirty-one years, and at near-by stations, including Provo, Thistle, Heber, and Park City, for eight to fourteen years. The most important meteorologic data, compiled from reports of the United States Weather Bureau, are summarized in the following tables, which give details of precipitation, temperature, wind velocity, humidity, and evaporation, on which the supply of underground water directly depends.

PRECIPITATION.

Monthly and annual precipitation at Salt Lake City, 1875 to 1904.

[Inches.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1875	3.05	0.79	2.81	1.50	2.91	0.90	1.01	0.25	1.22	1.36	5.81	2.03	23.64
1876	1.23	1.52	4.00	2.09	4.30	.00	.83	.92	.42	3.27	.81	1.80	21.28
1877	.87	.38	2.93	2.14	3.49	.80	.02	.28	.90	2.41	1.02	1.11	16.35
1878	1.07	3.49	2.54	2.63	2.50	.35	1.08	.81	3.15	1.39	.63	.11	19.75
1879	1.87	.71	.67	3.26	.10	1.34	.07	.06	.01	1.62	.32	3.08	13.11
1880	.29	1.02	.43	2.37	1.85	.01	.20	.74	.56	.40	1.17	1.90	10.94
1881	1.24	2.44	.88	2.37	2.55	.28	.21	1.61	.43	2.19	1.44	1.24	16.88
1882	1.50	.42	1.12	3.81	.26	2.24	.30	1.61	.37	2.89	.54	.92	15.98
1883	1.47	.72	1.75	2.92	.98	.33	.10	.62	.13	2.24	1.78	1.20	14.24
1884	.71	2.23	3.69	2.89	1.78	.33	.27	.73	1.91	.36	.50	2.12	17.52
1885	1.48	1.56	2.64	3.47	2.49	2.67	.58	.90	1.29	.59	3.10	.92	21.69
1886	1.01	1.36	2.60	4.43	.06	1.02	T.	.59	1.88	1.98	1.79	1.27	18.89
1887	2.36	1.41	.35	1.87	.73	.37	1.23	.69	.55	.30	.25	1.55	11.66
1888	1.52	1.22	2.18	.99	.34	.98	.24	.63	.51	.80	2.00	2.21	13.62
1889	.73	.81	1.64	1.52	2.97	.01	.08	.92	.52	3.85	1.04	4.37	18.46
1890	3.07	2.05	1.12	.94	.16	.32	.02	.79	T.	1.44	T.	.42	10.33
1891	.74	.76	4.66	1.49	.72	1.08	.47	.46	1.19	1.26	.90	2.19	15.92
1892	1.61	.68	2.21	1.90	1.65	1.21	T.	.05	.12	1.58	.72	2.35	14.08
1893	.82	1.64	2.68	2.72	1.68	.04	1.19	.71	1.30	1.02	1.18	2.37	17.35
1894	1.31	.83	1.73	1.67	1.22	1.38	.82	.87	2.87	1.01	.28	1.28	15.27
1895	1.32	.85	.81	.73	2.29	.99	.42	.02	.95	.24	2.44	.89	11.95
1896	1.26	.69	1.99	2.53	3.67	.25	1.35	1.47	.52	.70	3.15	.84	18.42
1897	1.16	3.81	2.20	2.00	.98	.52	.69	.33	.48	1.91	1.19	1.47	16.74
1898	.58	.38	1.71	1.30	4.19	1.45	.18	1.35	.15	1.57	1.95	1.28	16.09
1899	.84	2.98	2.93	.81	2.50	.96	.42	1.06	T.	2.85	1.52	.61	17.57
1900	.44	1.30	.33	2.91	.44	.08	.32	.72	1.44	1.99	1.40	.16	11.53
1901	.95	1.77	2.48	.87	4.27	.49	.31	1.22	.66	.98	.92	1.16	16.08
1902	.80	1.17	1.22	3.69	.33	.37	.56	.15	.05	.52	1.24	1.31	11.41
1903	2.11	.82	1.35	1.11	3.55	.74	.14	.43	.84	.81	2.21	.51	14.62
1904	1.45	2.25	3.99	2.20	3.08	.27	.59	.28	.12	1.18	.00	.90	16.31
Mean	1.44	1.33	2.03	2.21	1.62	.79	.53	.72	.93	1.54	1.36	1.64	16.19

Monthly and annual precipitation at Park City, 1899 to 1904.

[Inches.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1899	......	......	......	......	......	......	......	......	......	......	0.90	1.80	......
1900	0.93	1.87	0.38	3.56	0.30	T.	0.10	0.32	2.23	0.90	3.50	1.30	15.39
1901	2.24	2.35	3.15	1.92	1.50	0.20	.90	1.40	.45	.18	1.40	2.20	17.89
1902	1.90	1.18	4.04	1.96	.67	......	......	......	......	......	......	......	......
1903	3.88	1.34	2.60	.95	2.89	T.	......	......	.92	.30	.55	.95	......
1904	2.15	5.00	7.85	1.69	2.44	......	......	1.99	......	......	.00	......	......

Monthly and annual precipitation at Provo, 1899 to 1904.

[Inches.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1899	1.54	2.80	2.45	0.39	1.37	......	......	......	0.00	2.79	0.94	1.05	....
1900	.45	.35	.05	1.65	.32	......	......	......	1.13	.66	3.50	.12	....
1901	.22	2.06	1.09	.29	.39	0.18	T.	......	......	T.	.85	.98	....
1902	.35	1.12	1.30	2.14	.36	.10	0.11	0.20	......	.68	1.55	1.28	....
1903	2.65	.65	1.80	.51	2.69	.30	.39	.42	.72	.55	1.14	.49	12.31
1904	1.72	2.27	3.75	1.56	2.11	.42	.39	.45	.04	1.56	.00	1.05	15.32

Monthly and annual precipitation at Heber, 1899 to 1904.

[Inches.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1899	2.95	5.85	3.00	0.89	1.14	0.97	1.61	2.10	0.15	3.20	0.85	1.55	14.26
1900	1.06	1.50	.34	2.53	.16	.20	.25	.31	1.20	1.47	4.42	.22	13.66
1901	2.20	2.20	1.56	.31	1.72	.08	.40	2.06	.16	1.70	1.40	1.50	15.29
1902	.50	1.03	1.46	1.88	.49	.37	.15	.50	.45	.45	1.77	1.04	10.09
1903	2.17	.07	1.95	.78	1.42	.25	.69	.02	1.17	.76	1.90	1.33	13.32
1904	2.10	3.00	3.48	.96	2.01	.73	.29	.88	.16	1.22	.00	1.91	16.74

Monthly and annual precipitation at Thistle, 1899 to 1904.

[Inches.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1899	1.60	2.40	1.30	0.05	0.88	T.	......	......	......	0.40	2.08	......	....
1900	.30	.47	.00	1.77	.05	0.10	0.10	0.46	1.00	.75	1.80	0.30	7.10
1901	......	2.35	2.40	1.15	.85	.05	.11	3.05	.25	1.15	.93	2.00	....
1902	1.90	2.05	2.00	2.23	.35	.00	.35	.20	.85	.41	2.10	1.45	13.89
1903	......	......	......	1.75	1.60	.35	.53	.10	.66	1.43	.80	1.40	....
1904	1.90	1.55	......	.90	2.65	......	.32	.46	1.90	.27	.00	1.50	....

TEMPERATURE.

Mean monthly and annual temperature at Salt Lake City, 1873 to 1904.

Month	° F.	Month	° F.
January	27.9	August	74.8
February	33.0	September	64.3
March	41.6	October	52.3
April	49.5	November	39.8
May	57.8	December	32.7
June	67.0		
July	75.5	Annual	51.4

Mean monthly and annual temperature at Provo, 1890 to 1904.

Month	° F.	Month	° F.
January	26.6	August	70.7
February	29.3	September	59.8
March	39.3	October	48.7
April	49.1	November	38.4
May	58.0	December	29.2
June	64.7		
July	73.2	Annual	49.2

Monthly maximum temperature at Salt Lake City, 1899 to 1904.

[° F.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1899	54	51	67	80	83	96	97	91	91	73	63	59
1900	57	55	72	78	89	101	99	94	88	76	68	56
1901	51	55	65	79	88	90	101	95	86	85	67	59
1902	43	62	58	78	88	98	96	98	92	81	70	58
1903	53	42	65	80	86	91	96	98	92	77	70	45
1904	48	66	63	78	83	92	97	94	92	83	66	55
Mean	51	55	65	79	86	95	98	95	90	79	67	55

Monthly minimum temperature at Salt Lake City, 1899 to 1904.

[° F.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1899	16	−10	20	30	25	34	51	46	46	30	28	9
1900	20	10	26	30	40	47	53	52	32	27	28	2
1901	4	15	25	15	43	40	49	56	39	36	29	11
1902	− 4	12	21	32	35	42	43	52	35	36	21	15
1903	15	− 4	14	25	33	54	46	48	37	32	17	14
1904	7	6	19	30	36	44	51	46	38	28	26	7
Mean	11	10	21	27	35	44	49	50	38	32	25	10

WIND VELOCITY.

Average wind velocity at Salt Lake City, 1900 to 1904.

[Miles per hour.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1900	3.4	5.2	6.3	7.3	6.8	6.5	6.0	6.4	6.5	6.5	5.0	4.5	5.9
1901	5.0	4.0	6.2	7.8	7.3	6.6	6.3	5.8	7.0	5.0	4.9	4.8	5.9
1902	3.8	5.5	6.9	6.7	7.1	6.7	6.7	6.5	6.7	5.7	6.0	4.7	6.1
1903	4.8	4.5	6.8	7.3	6.1	6.6	7.2	6.2	6.3	5.3	5.4	3.7	5.8
1904	4.1	6.3	7.3	7.2	6.8	6.5	6.5	5.7	6.0	5.4	4.7	4.9	6.0
Mean	4.2	5.1	6.7	7.2	6.8	7.0	6.5	6.1	6.5	5.6	5.2	4.5	5.9

HUMIDITY.

Mean relative humidity at Salt Lake City, 1900 to 1904.

[Per cent.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1900	78	65	40	59	41	25	24	24	36	48	62	63	47
1901	69	73	55	42	44	36	26	39	30	50	57	71	49
1902	83	62	58	48	43	31	27	27	32	40	56	65	48
1903	73	74	52	44	48	38	30	28	38	45	64	75	51
1904	75	62	64	46	49	38	33	38	34	53	45	66	50
Mean	76	67	54	48	45	34	28	31	34	47	57	67	49

EVAPORATION.

Depth of evaporation at Utah Lake[a] *from August, 1903, to August, 1904.*

[Inches.]

Month	Inches	Month	Inches
1903.		**1904—Continued.**	
August	8.40	February	2.00
September	6.78	March	3.50
October	3.86	April	4.63
November	2.50	May	7.72
December	1.50	June	8.80
1904.		July	9.41
January	1.50	Total	60.60

SUMMARY.

The climate of the valleys of Utah Lake and Jordan River is controlled by their location in the central eastern part of the Great Basin, but is modified somewhat by the proximity

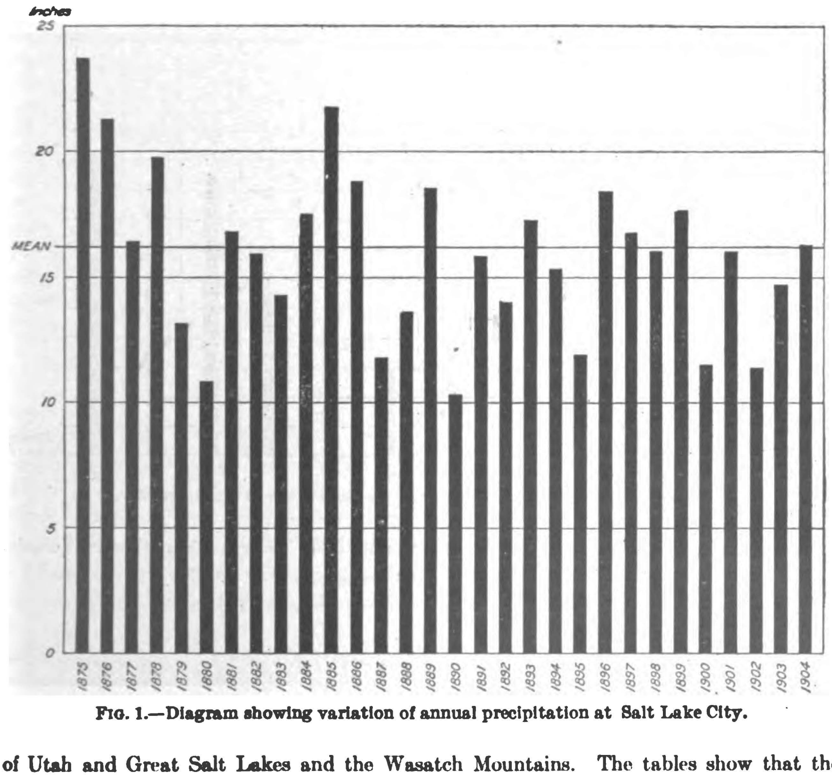


FIG. 1.—Diagram showing variation of annual precipitation at Salt Lake City.

of Utah and Great Salt Lakes and the Wasatch Mountains. The tables show that the climate is characterized by low annual precipitation, moderate temperature, moderate wind velocity, low relative humidity, and considerable evaporation.

The mean annual precipitation at Salt Lake City is 16.19 inches, ranging between a maximum of 23.64 inches in 1875 and a minimum of 10.33 inches in 1890. Since 1900 it has averaged 2.2 inches below normal (fig. 1). Only about 18 per cent of the annual total

[a] Computed from daily measurements of a tank 3 feet in diameter. Tests were made by the engineer of Salt Lake City from 1901 to 1903, and since then they have been kept up by the Reclamation Service under G. L. Swendsen. See also Newell, F. H., Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 154.

occurs from June to September, and for these four months amounts to less than 3 inches. Between October and May the variation is not marked, but the greatest precipitation occurs in March and April (fig. 2). This precipitation is unusually high for the Great Basin. The Wasatch Mountains serve to condense the moisture, originally derived in large part from the westerly winds from the Pacific Ocean, that remains in the air after crossing the Sierra Nevada.

Probably the precipitation is greater on the summits than at the stations where records have been kept, but data are not available. The melting snow of the winter's accumulation is the chief supply of the streams of the area under consideration.

The mean annual temperature of Salt Lake City is 51.4°. The mean monthly maximum ranges from 98° in July to 51° in January, while the mean monthly minimum varies between 10° in December and February and 50° in August.

The dryness of the atmosphere is indicated by the mean relative humidity of 49 per cent, varying from 28 per cent in July to 76 per cent in January, and by the amount of evaporation from a free water surface, which, according to the latest measurements, is about 60

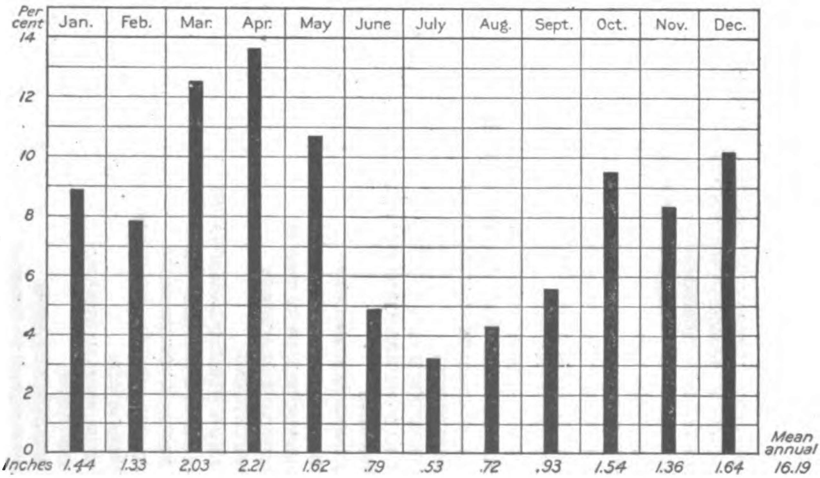


FIG. 2.—Diagram showing mean monthly precipitation at Salt Lake City.

inches a year. Yet the climate is not nearly as dry as in other parts of the Great Basin. The dryness lessens the effect of the summer's heat, so that the "sensible temperature" is not so great as would be suggested by the thermometer, being modified by the cooling effects of evaporation.

HYDROGRAPHY.

STREAMS TRIBUTARY TO UTAH LAKE AND JORDAN RIVER.

Seepage from surface streams, as shown hereafter, is the most important source of supply of underground water in the valleys of Utah Lake and Jordan River. A summary of discharge measurements therefore throws important light on the subject and, with other data, furnishes facts for roughly estimating the amount of water available for the annual replenishment of the underground reservoirs. The figures here given have been compiled from records of the United States Geological Survey and from data obtained through the courtesy of the city engineer of Salt Lake City, and are now published for the first time.

Satisfactory measurements of the flow of all the streams in the two valleys have not been made. However, records have been kept for a number of years of the discharge of several of the more important, and the combined data, with due consideration for varying conditions, may be taken as typical of the drainage of the entire watershed. The measure-

ments were made at the mouths of the canyons. Below these points, during the irrigation season, the water is diverted and conducted over the valley in an intricate system of ditches, so that the stream beds in their lower stretches are then often dry. During the flood season the streams discharge directly into either Utah Lake or Jordan River. Following are tables of monthly measurements for 1904, to which annual summaries for several years are added where figures are available:

Estimated discharge (at mouths of canyons) of streams tributary to Jordan River and Utah Lake.

CITY CREEK.

[Drainage area, 19 square miles.]

Date.	Discharge.			Total.	Run-off.			Rainfall.[a]
	Maximum.	Minimum.	Mean.		Per square mile.	Depth.	Relation to rainfall.	
1904.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*	*Per cent.*	*Inches.*
January	6.7	6.0	6.2	381	0.326	0.376	20.9	1.80
February	7.9	6.0	6.6	380	.347	.374	10.3	3.62
March	11.0	7.3	8.1	516	.442	.510	8.6	5.92
April	28.8	11.0	22.1	1,315	1.160	1.294	66.7	1.94
May	70.1	28.8	55.6	3,419	2.926	3.373	122.2	2.76
June	57.0	26.6	39.2	2,332	2.063	2.301	852.2	.27
July	26.5	16.2	19.7	1,211	1.037	1.195	202.5	.59
August	15.3	11.5	13.4	824	.705	.813	71.9	1.13
September	11.4	9.4	10.4	619	.547	.610	508.3	.12
October	9.3	8.7	9.1	609	.479	.551	46.7	1.18
November	8.7	8.2	8.5	506	.447	.499	....	.00
December	9.2	7.7	8.0	492	.421	.485	53.9	.90
Year	70.1	6.0	17.2	12,604	.908	12.381	61.2	20.23
1903	63.1	4.3	13.0	9,440	.685	9.323	63.1	14.77
1902	58.2	3.6	12.3	8,910	.647	8.811	69.5	12.67
1901	72.0	5.0	12.7	9,251	.668	9.126	53.9	16.94
1900	31.3	5.4	9.8	7,054	.517	7.040	52.5	13.41
1899	121.9	3.2	20.0	14,491	1.053	14.306	80.1	17.85

EMIGRATION CREEK.

[Drainage area, 19 square miles.]

1903.								
January	6.3	0.7	1.1	68	0.058	0.069	2.3	2.99
February	.8	.5	.6	33	.032	.033	3.1	1.08
March	11.7	.4	3.0	184	.158	.182	9.2	1.97
April	12.8	3.7	8.0	476	.421	.470	45.6	1.03
May	19.3	5.5	9.5	584	.500	.576	17.9	3.22
June	18.1	4.0	8.6	512	.453	.505	136.5	.37
July	4.0	1.6	2.8	172	.147	.169	120.7	.14
August	1.7	.6	1.0	61	.053	.061	14.2	.43
September	1.1	.6	.8	48	.042	.047	5.3	.88
October	2.0	1.1	1.2	74	.063	.073	13.3	.55
November	3.2	1.0	1.3	77	.068	.076	5.5	1.38
December	.8	.6	.7	43	.037	.043	5.9	.73
Year	19.3	.4	3.2	2,332	.169	2.304	15.6	14.77

[a] The record of rainfall given under City, Emigration, Parleys, and Mill creeks is the mean precipitation for Salt Lake City and Park City; that under American Fork and Provo River is for Provo and Heber; that under Spanish Fork is for Provo, Thistle, and Soldiers Summit.

Estimated discharge (at mouths of canyons) of streams tributary to Jordan River and Utah Lake—Continued.

PARLEYS CREEK.

[Drainage area, 50 square miles.]

Date.	Discharge.			Total.	Run-off.		Relation to rainfall.	Rainfall.
	Maximum.	Minimum.	Mean.		Per square mile.	Depth.		
1904.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*	*Per cent.*	*Inches.*
January	9.2	4.8	7.1	437	0.142	0.164	9.0	1.80
February	18.1	4.2	10.3	592	.206	.222	6.1	3.62
March	39.3	9.4	19.6	1,205	.392	.452	7.6	5.92
April	207.3	60.8	123.2	7,331	2.464	2.749	141.8	1.94
May	208.5	88.1	168.5	10,361	3.370	3.886	140.8	2.76
June	137.5	28.5	52.6	3,130	1.052	1.174	434.8	.27
July	41.1	19.5	26.1	1,605	.522	.602	102.0	.59
August	20.2	11.8	16.0	984	.320	.369	32.7	1.13
September	13.0	9.4	11.4	679	.228	.254	211.7	.12
October	13.7	11.8	12.9	793	.258	.297	25.2	1.18
November	11.8	8.8	10.3	613	.206	.230	....	.00
December	10.8	2.5	8.3	510	.166	.191	21.2	.90
Year	208.5	2.5	38.9	28,240	.777	10.590	52.3	20.23
1903	133.7	2.1	20.5	14,879	.410	5.581	37.8	14.77
1902	95.3	2.2	16.7	12,116	.334	4.544	35.9	12.67
1901	109.5	3.0	19.9	14,490	.398	5.429	32.0	16.94
1900	39.0	2.9	12.6	9,058	.251	3.431	25.6	13.41
1899	227.5	4.0	59.8	39,722	1.196	14.884	83.4	17.85

MILL CREEK.

[Drainage area, 21 square miles.]

1904.								
January	13.0	6.6	9.9	609	0.471	0.543	30.2	1.80
February	13.0	3.7	9.9	569	.471	.508	14.0	3.62
March	13.0	9.3	11.2	689	.486	.560	9.4	5.92
April	25.1	11.3	18.8	1,120	.895	.999	51.5	1.94
May	58.2	25.1	41.4	2,545	1.971	2.272	82.3	2.76
June	55.9	29.7	40.9	2,434	1.948	2.173	804.8	.27
July	29.7	20.8	25.7	1,580	1.224	1.411	239.2	.59
August	16.8	13.0	14.9	916	.710	.819	72.5	1.13
September	15.9	13.0	15.0	893	.714	.797	664.2	.12
October	14.0	13.0	13.7	842	.652	.752	63.7	1.18
November	13.0	11.3	12.4	738	.590	.658	....	.00
December	11.3	1.0	8.6	529	.410	.473	52.5	.90
Year	58.2	1.0	18.5	13,464	.878	11.965	59.1	20.23
1903	34.4	2.9	12.3	8,916	.586	7.964	53.9	14.77
1902	39.5	1.9	12.1	8,753	.575	7.814	61.7	12.67
1901	47.4	1.4	12.9	9,391	.615	8.383	49.5	16.94
1900	30.8	1.4	11.5	8,296	.549	7.466	55.7	13.41
1899	66.0	2.4	19.6	14,193	.932	12.669	77.1	17.85

Estimated discharge (at mouths of canyons) of streams tributary to Jordan River and Utah Lake—Continued.

BIG COTTONWOOD CREEK.

[Drainage area, 48 square miles.]

Date.	Discharge. Maximum.	Discharge. Minimum.	Discharge. Mean.	Total.	Run-off. Per square mile.	Run-off. Depth.	Relation to rainfall.	Rainfall.
1902.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*	*Per cent.*	*Inches.*
January	27.6	13.6	23.1	1,421	0.481	0.555	....	....
February	28.4	17.2	24.2	1,344	.504	.525	....	....
March	27.7	20.4	24.6	1,513	.512	.590	....	....
April	142.9	27.0	70.4	4,189	1.470	1.640	....	....
May	369.7	108.9	210.2	12,925	4.380	5.050	....	....
June	309.5	91.7	194.5	11,574	4.050	4.519	....	....
July	92.3	40.9	62.2	3,825	1.300	1.499	....	....
August	38.9	28.4	33.0	2,029	.688	.793	....	....
September	31.6	25.2	27.9	1,661	.581	.648	....	....
October	29.0	21.4	26.3	1,617	.548	.632	....	....
November	28.8	21.8	24.8	1,476	.517	.577	....	....
December	29.3	16.1	22.8	1,402	.475	.548	....	....
Year	369.7	13.6	62.0	44,976	1.292	17.576	....	....
1901	407.3	11.3	68.3	49,639	1.422	19.381	....	....

AMERICAN FORK.

[Drainage area, 66 square miles.]

Date.	Maximum.	Minimum.	Mean.	Total.	Per square mile.	Depth.	Relation to rainfall.	Rainfall.
1904.								
January	17	15	16.1	990	0.244	0.281	14.7	1.91
February	16	15	15.4	886	.233	.251	9.5	2.64
March	24	15	19.1	1,174	.289	.333	9.2	3.62
April	109	23	46.9	2,791	.711	.793	63.0	1.26
May	379	95	216.0	13,280	3.27	3.77	183.0	2.06
June	310	131	201.0	11,960	3.05	3.40	596.0	.57
July	147	66	95.3	5,860	1.44	1.66	488.0	.34
August	64	44	52.8	3,247	.800	.922	140.0	.66
September	43	35	38.1	2,267	.577	.644	644.0	.10
October	41	34	35.9	2,207	.544	.627	45.1	1.39
November	34	28	30.0	1,785	.454	.507	....	.00
December	28	18	25.3	1,556	.383	.442	29.8	1.48
Year	379	15	66.0	48,000	1.00	13.62	85.0	16.03

Estimated discharge (at mouths of canyons) of streams tributary to Jordan River and Utah Lake—Continued.

PROVO RIVER.

[Drainage area, 640 square miles.]

Date.	Discharge.			Total.	Run-off.			Rainfall.
	Maximum.	Minimum.	Mean.		Per square mile.	Depth.	Relation to rainfall.	
1904.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*	*Per cent.*	*Inches.*
January	290	196	244	15,000	0.381	0.439	23	1.91
February	861	253	373	21,460	.583	.629	24	2.64
March	667	331	388	23,860	.606	.699	19	3.62
April	680	353	486	28,920	.759	.847	67	1.26
May	2,153	461	1,145	70,410	1.79	2.06	100	2.06
June	1,625	371	1,131	67,300	1.77	1.98	347	.57
July	326	136	202	12,420	.316	.364	107	.34
August	182	134	149	9,162	.233	.269	41	.66
September	184	80	117	6,962	.183	.204	204	.10
October	146	79	113	6,948	.177	.204	15	1.39
November	190	113	139	8,271	.217	.242	....	.00
December	205	113	149	9,162	.233	.269	18	1.48
Year	2,153	79	386	279,900	.604	8.20	51	16.03
1898	1,212	146	386	279,000	.60	8.19	49	16.71
1897	2,600	225	[a] 571	414,000	.89	12.12	68	17.76
1895	1,760	192	423	306,400	.66	9.07	62	[a] 14.63

[a] Approximate.

SPANISH FORK.

[Drainage area, 670 square miles.]

1904.								
January	113	58	77.6	4,771	0.116	0.134	8.1	1.66
February	126	58	79.1	4,550	.118	.127	7.4	1.71
March	240	63	85.8	5,276	.128	.148	4.4	3.36
April	229	110	174.0	10,350	.260	.290	28.0	1.02
May	415	236	343.0	21,090	.512	.590	25.0	2.33
June	255	111	162.0	9,640	.242	.270	41.0	.66
July	121	80	94.6	5,817	.141	.163	39.0	.42
August	92	67	75.8	4,661	.113	.130	19.0	.69
September	75	65	68.0	4,046	.101	.113	13.0	.85
October	69	65	67.8	4,169	.101	.116	11.0	1.01
November	69	49	61.5	3,660	.092	.102	....	.00
December	77	40	54.3	3,339	.081	.093	8.7	1.07
Year	415	40	112.0	81,370	.167	2.28	15.4	14.78

Comparison of the discharge of several streams shows marked differences. For instance, during 1901 and 1902, the only years when complete measurements of both Parleys and Big Cottonwood creeks are available, the discharge of Big Cottonwood (drainage area, 48 square miles) averaged 47,308 acre-feet, while that of Parleys, with a drainage area slightly greater (50 square miles), averaged only 13,303 acre-feet. Again, during 1904 the discharge of City and Emigration creeks, each having drainage areas of approximately 19 square miles, amounted, respectively, to 12,604 and 2,332 acre-feet. Provo and Spanish Fork rivers also afford similar results. The drainage area of Provo River (640 square miles)

is slightly less than that of Spanish Fork (670 square miles), yet the discharge of the former in 1904 was more than three times that of the latter.

It will be noticed that the flows of Spanish Fork and of Emigration Creek, streams which in the above comparisons figured poorly, have much in common, though their drainage areas differ greatly. The flow of the two streams, expressed in second-feet per square mile of their drainage areas, averaged 0.167 for Spanish Fork and 0.169 for Emigration Creek, which may be compared with an average of 0.746 for City Creek and 0.69 for Provo River. The amount of discharge, expressed in depth of inches, over the watershed is 2.28 for Spanish Fork 2.30 for Emigration Creek, and 10.33 for City Creek. The run-off is approximately 15 per cent of the precipitation for Spanish Fork and Emigration Creek, and about 63 per cent for City Creek.

These and other discrepancies are due to a complex set of causes, chief of which are differences in precipitation, topography, vegetation, soils, and rocks of the several drainage areas, and the care that is taken to prevent fires, grazing, and destruction of timber on the watersheds. Though in general the main streams in the Wasatch Mountains have many features in common, the valleys of some of them are narrow and steep, while those of others are broader and more open. Some valleys are better adapted than others, by configuration and position, to collect and keep snow. Some of the streams head in lakes, while others do not. All are poorly clothed with trees, but some are less fortunate in this respect than others. The soil covering in general is thin, particularly on the steep slopes and in areas where the absence of much vegetation allows the products of rock disintegration to be washed into the valleys. But where the slopes are comparatively gentle and vegetation protects the accumulated rock débris, more of the precipitation is absorbed and (escaping flood discharge) seeps slowly into the valleys to maintain the perennial flow of the streams. Differences in the porosity of the bed rocks and in the character and quantity of débris in the stream beds, whereby greater or less amounts of water are absorbed, also greatly influence the amount of run-off.

UTAH LAKE.

Utah Lake is fed from several sources, including surface streams, seepage, springs beneath the lake, and the precipitation that falls upon it. The measurable factors were determined

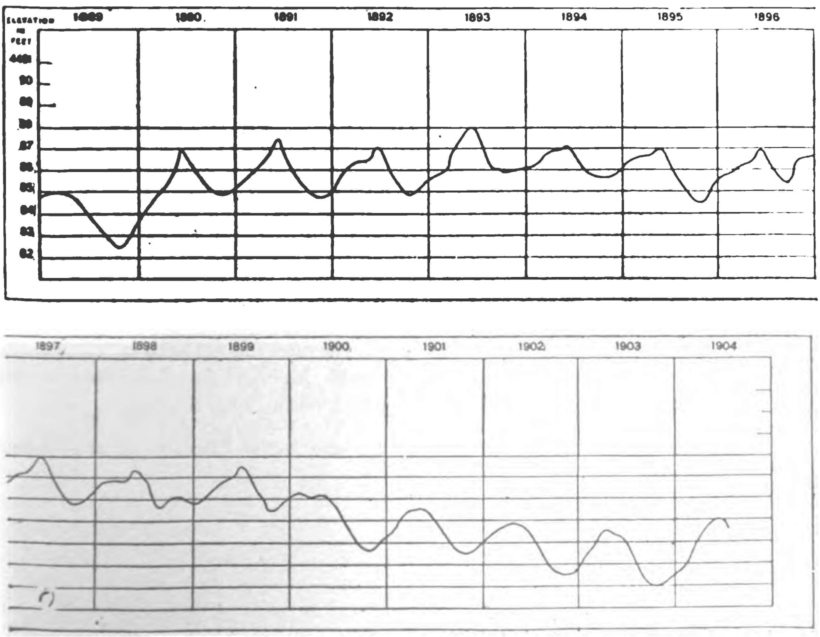


FIG. 3.—Diagram showing fluctuations of the surface of Utah Lake, 1889–1904.

for the period August 1903, to August, 1904, under the direction of G. L. Swendsen,[a] of the United States Reclamation Service, who found that of the total supply of 604,010 acre-feet only 471,140 were contributed by rainfall on the lake and by the measurable surface streams, leaving an unmeasured supply of 132,870 acre-feet. This considerable amount appears to be contributed by seepage and by springs, some of which have recently been found in the northwestern part of the lake.

The surface of the lake is subject to considerable variation in elevation in consequence of the changing relations of evaporation, precipitation, inflow, and outflow. Fig. 3, prepared by the Reclamation Service, shows fluctuations of the surface from 1889 to 1904.

There is a seasonal variation of 1 to 4 feet, ranging from a minimum in the late fall to a maximum in late spring and early summer. The diagram also shows the variation in the mean level of the lake. The lowest elevation shown occurred in 1903, when the lake was about half a foot lower than it was in 1889. Following 1889 was a period of ten years of relatively high water.

JORDAN RIVER.

During the last few years anomalous conditions have existed at the outlet of Utah Lake. The water level of the lake has fallen so low that the normal flow has ceased, and in order to supply the canals in Jordan Valley it has been necessary to resort to pumping. Accordingly a pumping plant has been in operation at the head of Jordan River since August, 1902. (Pl. IV, *A*.)

The following table of discharges has been prepared by Mr. J. Fewson Smith, jr., water commissioner:

Discharge of Jordan River and the canal systems in Jordan Narrows, and of Jordan River at pumping plant, April to October, 1904.

[Acre-feet.]

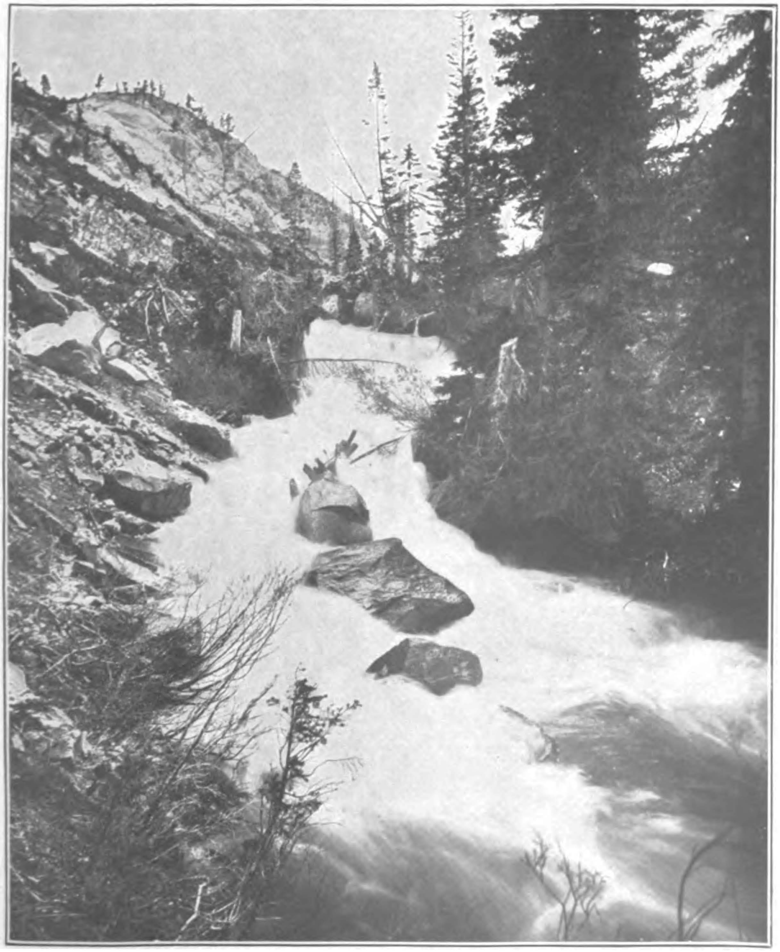
Month.	North Jordan.	East Jordan.	City.	South Jordan.	Utah and Salt Lake.	Jordan River at weir.	Sum of preceding.	Jordan River at pumping plant.[a]
1904.								
April	....	650	....	647	720	75	2,092	222
May	963	3,036	596	5,167	4,150	2,911	16,823	18,090
June	2,970	5,701	452	6,648	7,878	4,225	27,874	25,110
July	3,384	5,369	3,199	5,407	6,719	3,894	27,972	25,210
August	3,233	5,186	3,090	5,031	7,110	3,668	27,318	24,720
September	2,662	5,280	1,373	5,357	7,992	2,767	25,431	23,330
October	753	1,920	399	2,134	3,367	310	8,883	8,363
Total	13,965	27,142	9,109	30,391	37,936	17,850	136,393	125,045

[a] Figures furnished by G. L. Swendsen.

From these figures it appears that the gain in the flow of Jordan River between the pumping plant and the intake of the canals in Jordan Narrows, a distance of about 13 miles, April to October, 1904, was 11,348 acre-feet. The gain is partly supplied by seepage and partly by the flow of wells and springs. Between Jordan Narrows and the head of North Jordan canal, a distance of about 9 miles, Mr. J. Fewson Smith, jr., found that the seepage into Jordan River between May and September, 1904, amounted to 13,789 acre-feet.

[a] The writer acknowledges his indebtedness to Mr. Swendsen for many courtesies extended, both in the field and office, during the prosecution of the work.

A. GATE AT HEAD OF JORDAN RIVER.



B DEAD MAN'S FALLS, COTTONWOOD CANYON.

No systematic data have been collected below the head of North Jordan canal, but in December, 1904, the following measurements were made by Mr. Caleb Tanner and the writer:

Discharge of Jordan River and tributaries between Little Cottonwood Creek and the ford, in sec. 4, T. 1 N., R. 1 W., December 6–7, 1904.

		Second-feet.
Jordan River above mouth of Little Cottonwood Creek		61.38
Little Cottonwood Creek		8.14
Flume at Taylorville roller mill		39.0
Big Cottonwood Creek		51.2
Ditch south of Mill Creek		2.12
Mill Creek		23.94
Ditch, outlet of Decker Lake		2.93
Parleys Creek, north and south ditches		8.78
Eighth South street ditch		6.09
Total		203.58
Jordan River below North Temple Street Bridge	190.22	190.22
Loss between mouth of Little Cottonwood Creek and North Temple street		13.36
Outlet of Hot Springs Lake	7.64	
Sewer ditch (estimate)	7.50	
Jordan River at ford, sec. 4, T. 1 N., R. 1 W		214.00
Total	205.36	205.36
Gain between North Temple Street Bridge and ford		8.64

Loss in the flow of Jordan River, instead of expected gain, is thus shown between the mouth of Little Cottonwood Creek and North Temple Street Bridge at the time the measurements were made, while a slight gain is shown between the bridge and the ford in sec. 4, T. 1 N., R. 1 W. It appears that the seepage drains into the tributaries rather than directly into Jordan River in the area where the tributary streams are numerous and that farther north, where there are fewer tributaries, a small amount of seepage drains directly into the river. How far these figures represent conditions the year round remains to be determined.

GREAT SALT LAKE.

Except during a lapse from 1893 to 1896, instrumental records of the surface fluctuation of Great Salt Lake have been kept since 1875, and there is evidence less exact dating back to the survey of the lake by Stansbury in 1849–50. When that survey was made the level of the lake was extremely low, and since then it has varied considerably. In 1869 the water surface was approximately 11 feet higher than it was in 1850; a comparatively low stage was reached in 1873, after which the lake rose about 4 feet to a maximum in 1876, about equal to that attained in 1869. In 1883 the lake was about 7 feet below the maximum; then it rose 4 feet until 1886, since when it has gradually fallen until now it is at an extremely low stage, about 15 feet lower than the maxima of 1869 and 1876. Fig. 4 illustrates the changes since 1875.

Besides the irregular fluctuations there is a regular annual variation ranging between 1 and 2 feet, the maximum occurring in June and the minimum in the winter This annual variation is due to the changing relations of precipitation, inflow, and evaporation, high water occurring after the spring floods, and low water during the season of feeble stream discharge and after the period of excessive evaporation. The irregular variation of the past can be accounted for chiefly by changes in rainfall, the earlier maxima being associated with unusually large amounts of precipitation. The gradual decrease of late years in the volume of the lake, after allowing for recent dry seasons, is apparently due to largely increased irrigation, by which the inflow of surface streams has been checked

through diversion into ditches. Because of the considerable evaporation and transpiration incident to such use of the water, only a small per cent of the run-off reaches the

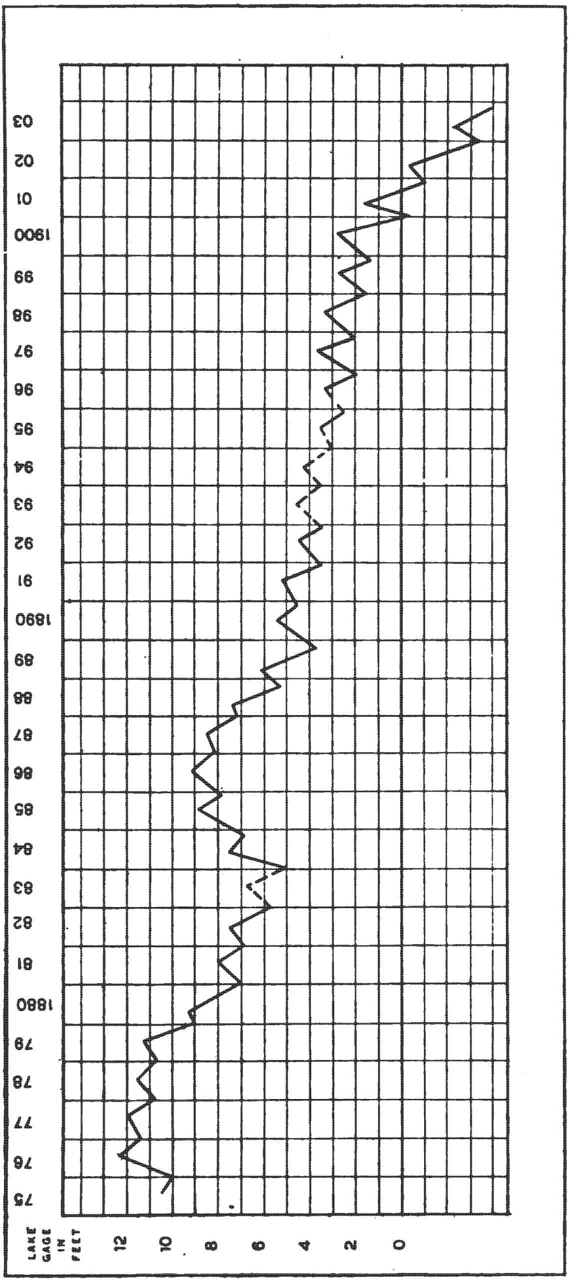


FIG. 4.—Diagram showing fluctuations of the surface of Great Salt Lake 1873–1903.

lake, and with the spread of irrigation it may be expected that this cause will increasingly tend to keep the lake level at a low stage.

UNDERGROUND WATER.

GENERAL CONDITIONS.

SOURCE.

The underground water supply in the valleys of Utah Lake and Jordan River, as is well known, is maintained by the snow and rain that fall on their drainage areas. In considering the sources of the supply, the precipitation tributary to Utah Lake and Jordan River can conveniently be divided into that on the mountains and that on the main valley.

It has been stated that the actual precipitation in the mountains probably exceeds the amount shown by the recorded data. Moreover, neither the rainfall nor the snowfall is evenly distributed. The precipitation is greater in the northern than in the southern half of the area under consideration, and in contiguous localities there are differences due to varying topographic conditions. More precipitation is likely to occur in the vicinity of the higher peaks, and in the mountain recesses that are well protected from the sun large quantities of snow linger long after the general mantle has disappeared.

Of the total precipitation on the mountains, part is evaporated, part joins the run-off, and part becomes underground water. Evaporation occurs either directly—from snow, from a free surface of water, and from water contained in soils and brought to the surface by capillary action—or indirectly by transpiration through the growth of plants. Of the portion which joins the run-off part runs directly out of the mountains, part flows to small lakes at the head of Big Cottonwood Creek and Provo River, and part is absorbed by the soil and rocks over which the streams flow and joins the subterranean store. A final portion of the precipitation on the mountains becomes underground water directly by absorption by the surface on which the rainfall occurs. Part of this underground water reaches the surface again by capillary action in the soils and by the life activity of plants and is finally evaporated; another part after remaining underground a shorter or longer time reaches the surface again by springs and seepage, and, joining the run-off little by little, maintains the perennial flow of the streams; another part joins the more permanent supply of underground water. It is impossible, because of the complexity of the subject and the lack of data, to state the amount of water which annually replenishes this more permanent supply of underground water, but the quantity is equivalent to the precipitation minus the run-off and the amount evaporated. From the incomplete facts at hand it appears that the run-off, measured at the mouths of the canyons, although varying greatly, approximates 50 per cent of the precipitation, but the total evaporation is unknown. Although exact figures representing the amount evaporated can not be obtained, yet experiments on evaporation from snow, soils, and vegetation in the mountain areas would afford valuable data.

The amount of precipitation in the valley is better known, and the figures for Salt Lake City and Provo are typical. Here, as in the mountains, part of the precipitation joins the run-off, part is evaporated, and part becomes underground water; but there are practically no measurements of these different quantities. Direct run-off of the precipitation on the valley is comparatively small, owing to the open nature of the country and to the fact that no great accumulations of snow occur, and the seepage run-off probably constitutes the main amount. Evaporation from soils and vegetation dissipates probably the largest part of the rain that falls on the valley, especially during the summer. The increase of the more permanent underground water supply due to the rainfall on the valley is consequently small. A basis for judgment is furnished by comparing the condition of the valley east and west of Jordan River. Precipitation is perhaps slightly less in the western part of the valley, but the difference is not enough to cause the marked contrast. The scarcity of ground water within easy reach of the surface in the western part of the valley, compared with the abundance easily accessible in the eastern part, implies that the rainfall on the valley contributes a proportionally small amount to the store of underground water. Existing conditions are due to the fact that on the west only a few feeble and generally intermittent streams are tributary to the valley, whereas on the east a number of large perennial streams flow from the Wasatch Mountains, supplying water that is distributed

over the valley by canals. Seepage from these streams is the main source of underground supply in the valleys.

The amount of water contributed to the valleys by streams from the Wasatch Mountains is capable of rough numerical statement. The drainage area in these mountains tributary to Jordan Valley is approximately 220 square miles, and measurements of five creeks in that region, given in the section devoted to hydrography, show an average flow of 0.66 second-foot per square mile of watershed. This amount is equivalent to a stream discharging 145 second-feet, or a total amount approximating 105,000 acre-feet a year. The average of measurements of Provo River and Spanish Fork in Utah Lake Valley gives a flow of 0.43 second-foot per square mile of drainage area, which, assuming the flow to be derived from rainfall on a watershed of about 1,670 square miles, is equivalent to a stream discharging 718 second-feet, amounting to 520,000 acre-feet a year.

Of this amount of water annually contributed by streams to the valleys of Utah Lake and Jordan River, part permanently runs off and is added to the supply of Great Salt Lake by Jordan River. This quantity has not yet been systematically measured, but it is estimated to average about 200 second-feet. The residue either evaporates, directly and indirectly, or becomes underground water. Unfortunately, no figures are available whereby the amount lost by evaporation can be estimated, so that the annual replenishment of the underground supply is unknown. Only the crude statement can now be made that, in the presence of influences sufficient to cause an evaporation of 60 inches a year from a free body of water, the amount which is not thus lost from a supply of somewhat more than 600 second-feet joins the underground store.

Seepage measurements which have been made at different times in both valleys from creeks and ditches offer concrete demonstrations of the manner in which the underground supply is maintained. Only a few such measurements have been made in Utah Lake Valley, but it has been shown that in 1½ miles the Timpanogas canal lost slightly more than 25 per cent of the water taken in at its head.[a] Another set of measurements has been made on Provo River. The discharge a short distance above the mouth of the canyon was found to be 175.04 second-feet; at a station a mile west of Provo the river was dry, while the sum of several intermediate diversions amounted to 186.22 second-feet. The difference—11.18 second-feet—represents the return seepage from the various canals.[b] In the valleys of creeks tributary to Jordan River more measurements have been made, of which those in Big Cottonwood and Mill valleys are typical. In Big Cottonwood Creek Valley Mr. E. R. Morgan selected for measurement two sections of the creek on which different conditions exist. In the upper section, immediately below the mouth of the canyon, the bed of the stream is composed of large loose bowlders resting on coarse gravel, and the land on either side is covered with comparatively scanty vegetation. In the lower section, below the head of Green ditch, the bed of the creek is comparatively smooth, and the land on both sides is irrigated and covered with abundant vegetation The loss in the first section, in a distance of 2½ miles, was 7.36 second-feet, a percentage of 22 6, while in the second section, also 2½ miles long, the loss was only 0.30 second-feet, a percentage of 2.4.[c] In Mill Creek Valley Mr. Morgan also made measurements in two sections where different conditions exist. In one section, 2 miles long, he found a loss of 22.7 per cent; in the other, three-quarters of a mile long, he found a loss of 3.6 per cent.[d]

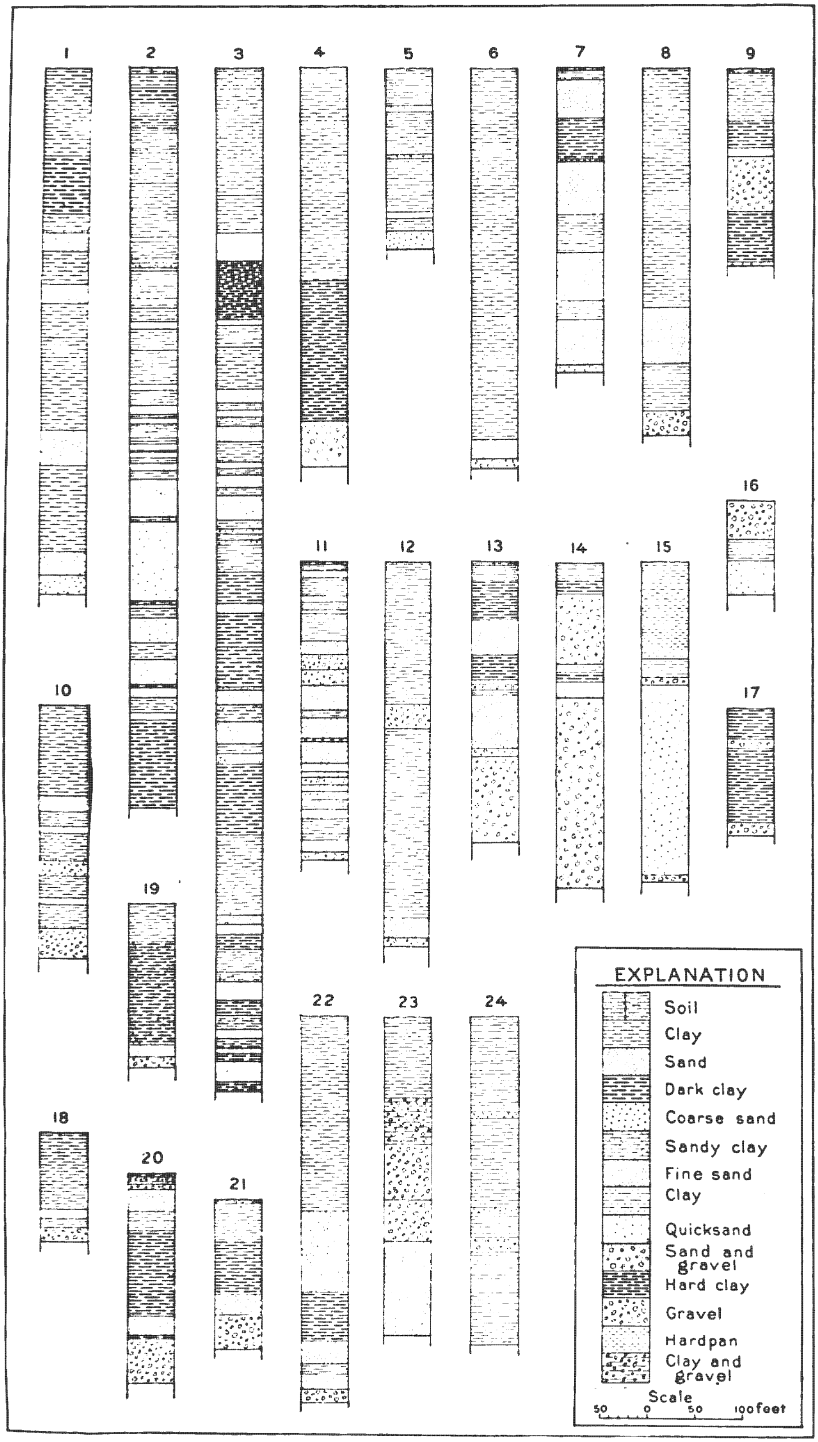
While seepage from the flow of the creeks and canals furnishes the chief supply of underground water to the valleys of Utah Lake and Jordan River, other sources are the underflow of the creeks at the mouths of the canyons, springs from bed rock, seepage at the base of the mountains, and the small addition, already mentioned, derived from rainfall on the valley. The underflow of the creeks at the mouths of the canyons is an important source, but the amount thus contributed is unknown. The quantity equals the remainder after subtracting the sum of run-off and evaporation from the precipitation, of which factors only the run-off is established, the precipitation being only approximately and the evaporation not at all known. The amount of the underflow can be directly determined, however, by a series

[a] Bull. U. S. Dept. Agric. No. 124, Office Expt. Stations, 1903, p. 123.

[b] Ibid., p. 126.

[c] Morgan, E. R., Irrigation in Mountain water district, Salt Lake County, Utah: Bull. U. S. Dept. Agric. No. 133, Office Expt. Stations, 1903, pp. 60–61.

[d] Ibid., pp. 44–45.



WELL SECTIONS.

No. 1, Oregon Short Line well at Kaysville; No. 2, Southern Pacific Company's well at Strongs Point; Nos. 3-24, location shown on Pls. VII and VIII.

of measurements which should be made in estimating the feasibility of constructing subsurface dams. The amount of water contributed to the valleys from bed-rock sources is also important. A remarkable series of thermal springs is associated with the great fault at the western base of the Wasatch Mountains. These occur at intervals along the entire extent of the range, and other warm springs, which may also be connected with faults, are located within the area under consideration. Association with faults suggests a deep-seated origin, which accounts for the high temperature of the water. The last source of the valley water supply to be mentioned is the comparatively small amount which is derived by seepage from the base of the mountains from areas that are not drained by creeks.

DISTRIBUTION OF UNDERGROUND WATER.

From the outline of the geology given on pages 7-13 it will be seen that the valleys of Utah Lake and Jordan River are occupied by a considerable but unknown thickness of gravel, sand, and clay derived from the disintegration of the adjacent mountains and deposited in the valley under alternating subaerial and lacustrine conditions. In general, the deposits are arranged in broad, sheet-like accumulations, the coarser-textured materials abounding adjacent to the highlands and the finer débris preponderating farther out. The beds lie practically flat in the center of the basins, but are inclined slightly away from their source, the attitude of deposition being practically unaltered. Conditions of deposition, however, were so varied that over large parts of the area considered the deposits are not widely uniform. For instance, while clay was being laid down in one place sand was accumulating in an adjacent area and at their border the two deposits were merged. Consequently the arrangement of the beds is broadly lenticular, as is illustrated by the well records (Pl. V). No two records are exactly alike, and in most cases it is impossible to correlate deposits in the different sections. Beds of clay are most widely distributed, but the more localized accumulations of sand and gravel, which are the most important reservoirs of underground water, are irregularly distributed.

Underground water derived from the sources stated above occupies the spaces between the solid particles of the clay, sand, and gravel which constitute the valley filling. In general, these deposits are saturated below the horizon which marks the surface of ground water. The position of this surface varies, depending on the supply, on the amount used or the intensity of evaporation, and on the character and slope of the sediments. The water is seldom stagnant, but tends to flow with extreme slowness from a higher to a lower level, the chief factors in the movement being the number and size of the interstitial spaces in the deposits and the pressure gradient due to gravity. The highest velocity of ground water ever determined is about 100 feet in twenty-four hours, but the ordinary velocity is much less than this, common rates in sand being between 2 and 50 feet a day.

The fluctuation of the surface of ground water is considerable. Since the chief replenishment of the supply occurs when the creeks discharge the most and when the irrigation canals are in full operation, ground water occurs nearer the surface in summer than in winter. Conditions in different areas cause a varied annual range, but 10 feet is common and 15 feet is not infrequent. In addition to the annual fluctuation a cumulative change is in progress, the ground-water surface being gradually raised in the lower parts of the valley in consequence of irrigation and the custom of allowing artesian wells to flow unceasingly, leading to swampy conditions in the valley bottom. Details regarding these changes are given on subsequent pages.

Pl. VI illustrates the approximate average depths at which ground water occurs in the valleys of Utah Lake and Jordan River. The boundaries between the different areas fluctuate and can not accurately be determined. A narrow belt contiguous to the base of the mountains is left blank on the map because of the varying and often unknown conditions that exist there, owing to seepage and the irregular distribution of water in the adjacent bed rocks. In the absence of topographic maps the position of the water table can not be shown by contours.

Below the surface of ground water the saturated beds contain varying amounts, depending on the character of the deposits. Coarse-textured gravel and sand, having a greater porosity than fine-textured clay, hold and transmit relatively more water. Beds of sand and gravel therefore constitute the chief underground reservoirs. Typical illustrations of the distribution of sand and gravel are shown in Pl. V. In sinking wells in this region, beds

of sand and gravel, ranging from a few inches to a hundred feet or more and separated by varying thicknesses of clay, are encountered, water being commonly found in each porous deposit. Because of the prevailing inclination of the deposits away from the mountains, and of the presence of relatively impervious beds of clay above more porous sand and gravel, the contained water is under pressure. In the lowland areas this pressure is sufficient to cause the deep-seated water, when it is reached in a well, to rise and flow at the surface, and consequently artesian water is an important source of supply. Above the lowlands, where the surface elevation is too great for a flow to occur at the surface, the water rises in deep wells to a greater or less height according to the amount of pressure.

QUALITY OF UNDERGROUND WATER.

The accompanying analyses, gathered from a number of sources and reduced to common terms, illustrate the character of the water in the valleys of Utah Lake and Jordan River.

Analyses of water from streams and springs in valleys of Utah Lake and Jordan River.[a]

[Parts per million.]

No.	Source and date.	Ca.	Mg.	Na.	K.	Al_2O_3	Fe_2O_3	SiO_2.	SO_4.	HCO_3.	CO_2.	Cl.	Total.
	CREEKS.												
1	City, Dec., 1882	55.3	18.9	2.6	24.3	2.0		19.9	7.3	......	95.1	19.5	244.9
2	Red Butte, Dec., 1882	88.8	31.3	25.6	Trace	3.3		35.2	100.6	......	108.8	22.9	416.5
3	Emigration, Dec., 1882	101.0	31.6	18.1	9.9	2.6		24.4	126.2	......	102.7	28.6	445.1
4	Parleys, Dec., 1882	85.1	22.5	31.5	2.6	1.8		27.2	56.5	......	122.1	19.7	369.0
5	Big Cottonwood, Oct., 1884	48.1	18.9	Trace.	8.6	1.6		12.6	42.1	......	63.6	7.9	203.4
6	Little Cottonwood, Oct., 1884	17.5	8.2	5.9	1.7	1.3		39.9	12.3	......	32.2	2.8	121.8
7	Dry Cottonwood	17.0	27.0	15.0	14.0	......	......	......	34.0	121.0	......	14.0	242.0
8	American Fork	45.0	24.0	4.0	10.0	......	......	......	42.0	145.0	......	Trace.	270.0
9	Payson	12.0	17.0	22.0	3.0	......	......	......	32.0	121.0	14.0	......	221.0
10	Santaquin	12.0	31.0	31.0	5.0	......	......	......	33.0	212.0	14.0	......	338.0
11	Currant	47.0	54.0	89.0	44.0	......	......	......	115.0	181.0	15.0	211.0	756.0
12	Warm	114.0	48.0	381.0	92.0	......	......	......	114.0	333.0	28.0	703.0	1,813.0
	RIVERS.												
13	Provo	51.0	29.0	28.0	22.0	......	......	......	44.0	205.0	......	28.0	397.0
14	Spanish Fork	68.0	36.0	46.0	17.0	......	......	......	64.0	277.0	......	28.0	536.0
	Jordan:												
15	Utah Lake (outlet), 1899	67.6	13.8	233.7	2.0	......	......	......	236.7	......	23.7	316.5	894.0
16	Salt Lake City (near), 1899	111.8	13.7	251.1	......	......	......	......	334.5	......	Trace	378.9	1,090.0
	WARM SPRINGS.												
17	Salt Lake City, Oct., 1881	535.2	138.4	3,039.0	178.0	0.7		21.3	787.5	......	442.9	4,968.0	10,284.0
18	Beck's (hot)	694.3	109.5	3,754.9	196.9	9.0	......	31.5	840.5	......	204.5	6,743.8	12,584.9
19	Sandy (8 mi. s.), Mar. 1882	141.5	27.7	405.0	55.0	5.1		50.5	53.8	......	272.7	635.6	1,658.0
	UTAH LAKE.												
20	1883	55.8	18.6	17.7	2.0	......	......	10.0	130.6	......	60.9	12.4	308.0
21	1904	67.0	86.0	230.0	22.0	......	......	28.0	378.0	194.0	11.0	337.0	1,353.0

[a] AUTHORITIES.—Nos. 1-5, 17, 19, Kingsbury, J. T. Nos. 6-14, Soil survey of the Provo area, Utah: Bureau of Soils U. S. Dept. Agric., 1904, p. 22. Nos. 15, 20, and 21, Cameron, F. K. Water of Utah Lake: Jour. Am. Chem. Soc., vol. 37, No. 2, 1905. No. 16, ibid., Rept. No. 64 U. S. Dept. Agric. No. 18, Riggs, R. B., Bull. U. S. Geol. Survey No. 42, 1887, p. 148. No. 20, Clarke, F. W. No. 21, Brown, R. E.

The average of analyses of 12 streams[a] coming from the Wasatch Mountains shows a total solid content of 319 parts per million, ranging from 122 to 536, the varying character of the water being due to differences in the rocks of the respective watersheds. Examination of these analyses shows that calcium is usually the most abundant base, with magnesium a poor second, while sodium and potassium generally are much less plentiful and vary in relative amounts. Among the acid radicals, carbonic commonly preponderates, being often several times more abundant than the others; sulphuric ranks next, and in a few streams is important, while chlorine is generally of minor occurrence. Little Cottonwood Creek ranks first, having only 121.8 parts per million of dissolved solids. It flows for most of its course through granitic rock and therefore contains but little calcium carbonate. The total solids in Big Cottonwood Creek water are also low and relatively little lime is present because a large part of the drainage is over silicious rocks. The great abundance of limestone on most of the watersheds accounts for the abundance of calcium carbonate. Red Butte, Emigration, and Parleys creeks make a relatively poor showing, the sulphates being especially abundant, because these streams flow over Permo-Carboniferous and Mesozoic rocks containing more or less gypsiferous matter. Provo River and Spanish Fork drain large areas occupied by a variety of rocks, among which limestone is prominent, and the analyses show rather high amounts of total solids, the carbonates being particularly abundant. Currant and Warm creeks are exceptional. The unusual amount of sodium chloride present in Currant Creek is derived from salt deposits above Nephi. Warm Creek rises in the springs west of Goshen, and the character of its water, like that of similar springs in this area, is due to unusual conditions.

The few analyses of the thermal springs in the area under consideration show the presence of abundant dissolved salts, of which the chlorides are the most plentiful, though considerable quantities of sulphates and carbonates are also present. Sodium is several times more abundant than any other base, calcium ranks second, and magnesium and potassium are present in small amounts. Some of the hot springs contain considerable hydrogen sulphide. Most, if not all, of these springs are associated with faults and have a deep-seated origin, to which their temperature and composition are due. The mineral matter is leached from the deposits through which the waters pass, much of the salt content being probably derived from old lake beds.

Analyses of water from flowing wells are similar to those of surface streams. Different wells give different results, the quality of the water varying with the source and the nature of the deposits passed through underground. Analyses from the "Murray" and "Germania" wells show an unusually small content of total solids, while those from the wells of the Utah Sugar Company at Lehi and near Provo show amounts above the average. In the area contiguous to Great Salt Lake the well water contains considerable salt, but no analyses were obtained. In general the water from flowing wells is of admirable quality and often forms a marked contrast to the supply from shallow wells.

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[a] Omitting Currant and Warm creeks, which are exceptional.

Analyses of water from wells, etc., in valleys of Utah Lake and Jordan River.[a]

[Parts per million.]

No.	Source and date.	Ca.	Mg.	Na.	Al_2O_3. Fe_2O_3.	SiO_2.	SO_4.	CO_3.	Cl.	Na_2CO_3 K_2CO_3.	Na_2SO_4 K_2SO_4.	NaCl KCl.	Total solids.
22	Mill Pond at Lehi, July, 1895.	82	54	.....	16.0	11	[d] 196	[b] 135	....	124	30	152	800
23	Artesian well, Murray Plant, Am. Smelting and Refining Co.	23	6.6	.....	1.4	14	[d] 14	42	....	.....	Tr.	11	114
24	Artesian well, Germania Plant, Am. Smelting and Refining Co.	24	8.7	.....	1	9.7	[d] 12	64	....	.....	6.8	28	140
25	U. S. Mining Co. well, Bingham Junction, Aug., 1902.	37	13	.....	2.4	14	[d] 50	56	....	.....	27	87	290
26	U. S. Mining Co. well, West Jordan, Aug., 1902.	11	5	.....	1	13	......	[c] 30	68	.....	44	58	232
27	Wm. Cooper's well, Bingham Junction	34	11	.....	1.2	16	[d] 16	66	....	.....	45	87	284
28	Beet-cutting station, Utah Sugar Co. well, near Provo, Jan., 1899.	74	29	.....	5	58	......	[c] 180	89	.....	116	103	656
29	Artesian well, Utah Sugar Co., Lehi, Jan., 1899.	62	38	.....	Tr.	12	154	[c] 91	21	.....	.....	287	648
30	R. G. W. Rwy. well, Springville, May, 1901.	157	19	14	4	18	41	120	21	.....	.....	.....	.....
31	R. G. W. Rwy. well, Goshen, May, 1901.	85	32	104	90	80	47	127	160	.....	.....	.....	.....

[a] AUTHORITIES.—Nos. 22, 28, and 29, Dearborn laboratories. Nos. 25 and 26, Converse, W. A. No. 27, J. H. Parsons Chemical Co. Nos. 30 and 31, De Bernard, J. H.
[b] From $MgCO_3$.
[c] From $CaCO_3$ and $MgCO_3$.
[d] From $CaSO_4$.

No analyses of ground water obtained from shallow wells are available, but the general character of such water is known. In the upland areas above the canals the water from shallow wells is much like that commonly obtained throughout the region in deeper ones; it contains a moderate amount of dissolved salts, largely calcium carbonate, and is usually of good quality. But in the lowlands the surface water is quite different, generally containing considerable dissolved salts, among which alkalies are abundant. Where ground water lies within the scope of capillary attraction from the surface, evaporation causes the mineral matter which is held in solution to accumulate, and in this manner the soil becomes tainted with alkali. Consequently the water from surface wells in the lowlands is characteristically rich in dissolved salts.

Abnormal conditions prevail locally in the vicinity of the smelters in Jordan Valley south of Salt Lake City. Smelter smoke has lately become a nuisance to farmers by injuring crops and animals in the path of prevailing winds. Sulphur dioxide is the most abundant deleterious substance contained in the smoke, and to a minor extent locally finds its way into the water supply. Occasionally also ground water may become poisoned from accumulations of flue dust containing copper and arsenic.[a]

Natural gas occurs in a number of water wells in the area under consideration. Well drivers report the common presence of vegetable matter, chiefly fragments of wood, at different depths in many localities. This was entombed in the old lake deposits, and its decomposition may account for the origin of the gas. Though gas occurs in numerous wells it has been found in quantity in only a few localities, the greatest development occurring near the shore of Great Salt Lake, about 12 miles north of Salt Lake City.[b] Here several wells were drilled averaging about 500 feet in depth; and from September, 1895,

[a] Widtsoe, J. A., Relation of smelter smoke to Utah agriculture: Bull. Agricultural College of Utah No. 88, 1903.
[b] Richardson, G. B., Natural gas near Salt Lake City: Bull. U. S. Geol. Survey No. 260, 1905, p. 480.

to March, 1897, Salt Lake City was supplied with natural gas from this source, the total yield being approximately 150,000,000 cubic feet. But the supply finally became insufficient and the field was abandoned. Gas continues to be found in various parts of the valley and possibly other fields similar to that north of Salt Lake City may yet be found; but there is little reason for expecting much better results than already obtained and it is impossible to predict the localities where such supplies may be found.

The water of Utah Lake represents the varied sources of its supply; part is derived directly from surface streams, another part from seepage, still another portion from springs, and the whole is concentrated by evaporation. The analysis by the Bureau of Soils on page 30 shows the present condition of the water. Sodium predominates, magnesium and calcium are subordinate, and the corresponding salts are principally sulphates and chlorides. Comparison with an analysis of Utah Lake by F. W. Clarke twenty-one years earlier affords interesting data.[a] The total solids have increased from 308 to 1,353 parts per million, and the character of the water has changed from a preponderating sulphate solution to one containing large amounts of chlorides; the sodium has increased remarkably and magnesium is now in excess of calcium. These changes appear to be mainly due to man's occupancy of the region. The streams have been diverted for irrigation and an increasing supply has reached the lake as seepage after passing through the alkaline soils of the lowlands. Evaporation in the shallow lake also has tended to concentrate its waters.

The composition of the water of Great Salt Lake has been the subject of much investigation, and a list of the more important analyses is given on page 34. The lake receives the drainage of an enormous area, but by far the greater part of its supply is derived from the Wasatch Mountains, from Bear, Weber, and Jordan rivers. The mineral content of Great Salt Lake is the result of the concentration of a vast body of water during a long period of time, in which Lake Bonneville has given place by evaporation to the present lake. Great Salt Lake is shallow, and the seasonal and annual fluctuations in its level cause considerable differences in volume, with consequent changes in composition of the water. These changes are indicated by the increase of salinity from 13 per cent in 1873 to about 24 per cent in 1892.

In August, 1892, the water of Great Salt Lake contained 238 parts per thousand of total solids, consisting of predominating sodium and smaller amounts of magnesium, potassium, and calcium, in the order named, the corresponding salts being chlorides and sulphates. The water of the lake is thus a concentrated brine, and in the winter months the point of saturation for sodium sulphate is actually reached and crystals of mirabilite[b] are deposited. The critical point for calcium carbonate is passed, so that, in spite of its abundance in the waters that supply the lake, none has been found in it. Apparently calcium carbonate is precipitated soon after entering the dense body of water.

[a] Cameron, F. K., Jour. Am. Chem. Soc. vol. 37, 1905, p. 113.
[b] Talmage, J. E., "Great Salt Lake, Present and Past," 1900, p. 64.

Analyses of water of Great Salt Lake. [a]

[Parts per thousand.]

Analyst and date.	Ca.	Mg.	Na.	K.	SO_4.	Cl.	B_2O_3.	P_2O_5.	Total.	Specific gravity
Gale, L. D., 1850	Trace.	0.6	85.3	....	12.4	124.5	....	....	222.8	1.170
Allen, O. D., summer, 1869	0.2	3.8	49.6	2.4	9.9	84.0	Trace.	Trace.	149.9	1.111
Bassett, H., Aug., 1873	.6	3.0	38.3	9.9	8.8	73.6	....	....	134.2	1.102
Talmage, J. E.:										
Dec., 1885	.4	2.9	58.2	1.9	13.1	90.7	....	....	167.2	1.122
Aug., 1889	.8	5.1	65.3	2.1	11.7	110.5	....	....	195.5	1.157
Waller, E., Aug., 1892	2.424	2.844	75.825	3.925	14.964	128.278	Trace.	....	[b]238.12	1.156

[a] Waller, E., Water of Great Salt Lake: School of Mines Quart., vol. 14, 1893, p. 59.
[b] By evaporation, duplicate test gave 237.93.

Too little care is given to the sanitary character of the waters in the valleys of Utah Lake and Jordan River. The mountain streams are a source of excellent purity, yet they are liable to contamination. General supervision of the watersheds of the creeks that supply Salt Lake City is maintained by the municipality, especially on City Creek, but elsewhere few precautions are taken to safeguard the supply. Commonly the character of water obtained from the deep wells is of good quality, as is also that of surface wells in the thinly settled uplands adjacent to the base of the mountains. But surface water generally, especially in the thickly settled lowlands, where, moreover, the mineral content is high, is undesirable for domestic use because of its liability to contamination.

Salt Lake and Provo are the only cities in the area that have sewer systems. The Provo sewer discharges through an open ditch into Utah Lake, and thereby pollutes that body of water. Salt Lake City's sewage is well disposed of on a "sewer farm" below Hot Springs Lake, and the surplus enters Jordan River near its mouth. Elsewhere no systematic sanitary precautions are taken, and locally conditions are bad, with consequent frequent typhoid fever epidemics.

It can not be too strongly impressed upon inhabitants of country districts that the welfare of the community is intimately concerned with preserving the water supply uncontaminated, and in this connection it may be of service to reproduce a section from the ninth annual report of the Massachusetts State board of health: [a]

There are a few points to be borne in mind with reference to water supply, drainage of houses, and sewerage, which have been suggested by the examination of the board in this State, and may properly be summarized here.

1. The privy system, so common throughout the State, by which filth is stored up to pollute the air, soil, and water near dwellings, should in all cases be abolished.

2. Cesspools, unless extraordinary precautions be taken as to ventilation and prevention of pollution of soil and air, are little better, and should be given up for something less objectionable as soon as practicable.

3. Wells can not be depended on for supplies of wholesome water unless they are thoroughly guarded from sources of surface and subsoil pollution. Some of the foulest well water examined by the board has been clear, sparkling, and of not unpleasant taste.

4. Where wells have already been polluted and it is not practicable to dig new deep wells remote from sources of contamination or to introduce pure public water supplies, the storage of rain water, properly filtered, is a satisfactory method of procedure.

5. In small towns where public water supplies have not been introduced, and, indeed, wherever water-closets are not used, some method of frequent removal and disinfection with earth or ashes should be adopted in place of privies, by which it should be impossible for the filth to soak into the soil or escape into the air. Cemented vaults are not always to be depended upon, as their walls crack from frost or through settling of the ground, and they thus sometimes become sources of pollution of wells, besides contaminating the air. Nor is the fact of a privy being on a downward slope from the well a sufficient safeguard, for even then the direction of the subsoil drainage may be toward the well.

[a] Rafter, G. W., and Baker, M. N., Sewage Disposal in the United States, 1894, p. 40.

6. Earth closets, with proper care, may be satisfactorily adopted, but the earth, after having been once used, should be placed upon the land, not stored within doors and dried to be again used, for in the process of drying there are emanations from it which are, perhaps, not less dangerous from the fact of their being imperceptible by the unaided senses or through chemical examination. With earth closets a plan similar to that in use at the Pittsfield Hospital [a] may well be used for the chamber slops, and the kitchen waste may be utilized (with the chamber slops too, if desired) in the manner used by Mr. Field and Colonel Waring. * * * Less intricate methods are used in scattered dwellings, but with the effect of having the slop water absorbed by the ground and taken up by vegetation so far from the house as not to involve a nuisance or danger to health.

7. Where water supplies, water-closets, etc., are introduced, sewers should follow immediately in most kinds of soil. Cesspools should not be used, unless with extraordinary precautions; but with a few hundred feet square of lawn the irrigation system by agricultural drain pipes is to be recommended, whereby the filth is at once taken up by the roots of grass. In all cases, of course, with or without cesspools, there should be thorough ventilation of the system of house drainage, with disconnection from the main outlet drain by means of either a ventilating pipe or rain-water spout between the sewer trap and the house, and whose openings at the top should be only at points remote from windows and chimney tops.

On the whole, a thoroughly satisfactory arrangement of this kind, if properly looked after, is in many respects to be preferred to connecting with public sewers.

RECOVERY OF UNDERGROUND WATER.

A crude estimate of the amount of underground water in the valleys of Utah Lake and Jordan River might be made, based on an assumed thickness and porosity of the unconsolidated sediments, and the result would be many cubic miles, yet the figures would be valueless. The important fact is the amount of available water that can be recovered economically; but, unfortunately, this too, because of lack of detailed knowledge concerning the distribution and thickness of the beds of sand and gravel which constitute the reservoirs, can not be determined. Though definite figures are not available, the general fact is well known that the lowlands are amply supplied with underground water within easy reach of the surface and that on the highlands the underground supply is relatively small.

Underground water becomes available for use both naturally and artificially. It reaches the surface again naturally in springs and by seepage into drainageways, and is commonly recovered artificially by means of wells, though occasionally tunnels and subsurface dams prove efficacious. Wells are the main recourse in the area under consideration, and they can be conveniently grouped into two classes, flowing and nonflowing.

The areas in which flowing wells are obtained in the valleys of Utah Lake and Jordan River are shown on Pls. VIII and IX, and the list of wells, together with the descriptions of the different localities, gives detailed information concerning the occurrence of artesian water.

The date when the first flowing well was put down has not been ascertained, but it appears to have been about 1878. Since then many have been sunk, and the limits of the areas in which flows can be obtained have been determined with fair accuracy by experiment. The map shows that flowing wells exist only in the lower portions of the valley, the area of flows corresponding closely with that in which ground water lies within 10 feet of the surface. Higher up on the benches the elevation is too great to obtain flows.

Locally, flowing wells may be obtained at a depth of less than 50 feet, but generally they range between 100 and 400 feet, while the few that have been sunk to 1,000 feet and more encountered water under pressure in the successive beds of sand and gravel. As many as 25 distinct water horizons from which flows at the surface were obtained are reported in the Rudy well, sec. 6, T. 1 N., R. 1 W. The wells are usually 2 inches in diameter, though occasionally the shallower ones are only 1 inch, while the deeper ones are 4 and 6 inches. In yield the wells vary considerably, according to location, depth, and size of pipe. The greatest flow measured was that in the Harry Gammon well, sec. 7, T. 6 S., R. 2 E., which supplies about 266 gallons a minute from a 3-inch pipe. A number of wells flow less than 1 gallon a minute, though a common yield is between 10 and 60 gallons. The pressure is comparatively low, the highest measurements obtained being only 15½ pounds per square

[a] Cottage Hospitals: Ninth Ann. Rept. Mass. State Board of Health, pp. 83-95.

inch, and generally the greatest pressures are little more than sufficient to raise the water into railroad tanks.

Temperature measurements of the water from flowing wells afford some data bearing on the downward increment of heat in the unconsolidated valley deposits, but there are a number of disturbing factors. Adjacent to the mountains the waters are unusually cool; the presence of hot springs tends to disturb conditions, and the depths from which the waters flow are often not known. The common rate of downward increase in temperature appears to be slightly less than 1° F. in 50 feet, but the facts obtained do not warrant a closer statement. It may be of local interest, however, to observe that in general the temperature of the water increases with the depth of the wells at approximately that rate.

Few measurements have been made, but it is common experience that the yield of many flowing wells in the area under consideration has decreased. The most comprehensive measurements are those made of the wells owned by Salt Lake City near Liberty Park (p. 44). Comparing the discharge of 12 of these wells in August, 1890, with the yield of the same wells in September, 1902, it appears that in the interval of twelve years the flow of one had increased, but that those of the others had materially decreased. Such decrease, however, may be due largely to clogging of the pipes, for the total yield of the Liberty Park area has been maintained with little decrease by sinking new wells.

Decrease in yield is conspicuously apparent in Lehi and Spanish Fork, where flowing wells formerly could be obtained much more generally than now, and is notable elsewhere throughout the valley, especially adjacent to the boundary of the flowing area. Decrease in flow of individual wells is sometimes due to clogging up with sand and clay, and often can be remedied by cleaning or by the use of casing. But the general decrease is to be explained chiefly by the large increase in the number of wells which draw on the general supply. It is also to be remembered that for the past few years the annual precipitation has been considerably below the mean.

The artesian wells are used for stock, irrigation, and domestic purposes. The amount used for stock is comparatively small, and, save for watering small gardens, artesian water as yet is not extensively used for irrigation, except locally. Probably over a thousand acres are thus irrigated in Utah Lake Valley, the principal areas being below Lehi and Payson. The artesian supply is much used for domestic purposes, and in general furnishes an admirable quality of water, containing much less dissolved salts and being much purer than shallow ground water.

An attempt was made to estimate the total number of flowing wells in the area studied, but the result is to be taken only as a rough approximation. There are about 5,000 flowing wells in the valleys of Utah Lake and Jordan River, and possibly somewhat more than half of these occur in the southern valley. Assuming an average of 15 gallons a minute, a total yield of about 150 second-feet is thus indicated.

Outside of the area in which flowing wells are obtained underground water is recovered either from shallow dug wells that tap the upper surface of underground water or from driven wells in which the water comes from a relatively deep horizon and is under pressure which causes it to rise toward the surface. To save the expense of "driving," shallow wells are often dug within the area in which flowing wells can be obtained. Occupying the center of the valley and extending approximately to the limit at which flowing wells can be obtained, ground water lies within 10 feet of the surface, and locally, as has been mentioned, swampy conditions exist. As the base of the mountains is approached the depth to ground water increases and is over 50 feet on much of the upland where, over large areas, the distance to water is unknown.

Water is recovered from these wells generally by buckets and hand pumps. Comparatively few windmills are in operation. An average wind velocity of not less than 6 miles an hour[a] is stated to be required to drive a windmill; and since the mean wind velocity at Salt Lake

[a] Wilson, H. M., Pumping for irrigation: Water-Sup. and Irr. Paper No. 1, U. S. Geol. Survey, 1896, p. 27.

City from June to September, inclusive, is 6.5 miles an hour and for the entire year averages only 5.9 miles, the natural conditions are not very favorable for this form of power. Steam pumps are used only to a limited extent. The Bingham Consolidated Company has three 3-inch wells 250 to 300 feet deep in which the water rises to within about 70 feet of the surface; 125 gallons per minute are reported to be supplied by each, the water being raised by compressed air. Another instance of successful pumping is at the brickyard in sec. 29, T. 1 S., R. 1 E., where 40 gallons a minute are reported to be obtained from a well 30 feet deep. Gasoline for pumping has not been much used. Electric power can be cheaply developed in the canyons and affords a valuable asset. In the valleys of Utah Lake and Jordan River pumping on a large scale has not yet been resorted to. There is, however, a considerable quantity of water within easy reach of the surface which probably will not much longer remain unused.

Underground water is recovered in exceptional circumstances by means of subsurface dams, or similar contrivances, which impound the underground supply. In unconsolidated materials, in order that this may be successfully accomplished, certain conditions are necessary. Practically impervious bottom must exist within easy reach of the surface to prevent excessive lowering of the ground-water level, and competent side walls, not too far apart, should be present to intercept lateral escape. The presence of the necessary conditions can be determined only by prospecting, and the practicability of such structures is an independent question, but because of the value of water in the area under consideration their feasibility should be investigated. Possible locations of subsurface dams are suggested by rock walls at the mouths of the narrow canyons, where borings in search of suitable bottom should be made. Tests of the amount and porosity of the valley filling at and above the mouths of the canyons, together with measurements of the velocity of the underflow, would indicate the quantity of available underground water. On Emigration Creek, for instance, the comparatively low run-off, suggesting an unusual amount of underdrainage, and the quantity of water obtained from the inefficient city trench invite further testing of the possibilities. Below the mouths of the canyons in the several creek valleys favorable conditions also may be discovered by the drill to warrant the construction of infiltration galleries.

In the section devoted to geology it is stated that the rocks of this region are more or less disturbed and broken, and an important part of the precipitation on the mountains finds its way into the bed rock. The water occurs in the small interstices or pores which are present in all rocks, in larger spaces such as fissures or solution channels, and along joints, bedding planes, and igneous contacts. As would be expected, less water is found in the Oquirrh Mountains than in the Wasatch. Bingham is a dry camp, though more or less water is encountered in the workings, while the mines of Park City are wet. The Ontario tunnel, which drains most of the large mines of the latter district, is stated by J. M. Boutwell to discharge from 6,000 to 9,000 gallons a minute. Considerable water is being recovered by tunnels driven into bed rock along the base of the mountains. In some instances the site of the tunnel marks the presence of a former spring, as, for instance, Wadleys, near Pleasant Grove, and those in Butterfield Canyon. But in one, the Dalton and Lark tunnel, east of Bingham, water in quantity was not encountered until several thousand feet of rock were penetrated.

Another method of recovering water from bed rock is suggested by the structure of the mountains southeast of Salt Lake City. It will be recalled from the outline of the geology that a great syncline, modified by local undulations, is there developed, whose axis extends along the valley of Emigration Creek. The general structure is favorable for the occurrence of artesian water, but there are unfavorable complications. The rocks are chiefly compact limestones, the general disturbed and fissured conditions tend to relieve the pressure on the interstitial water, and the Wasatch fault has cut across the strata. Nevertheless, it is possible that locally the red sandstones contain water under pressure, but because of the limited intake area a large supply is not to be expected.

SUGGESTIONS.

It is evident that in general a high degree of efficiency in the use of the water resources of the valleys of Utah Lake and Jordan River is not maintained. Conditions can be greatly benefited by preventing waste whenever possible. Most prominent in this connection is the conservation of storm waters. Besides the construction of large impounding reservoirs small ones can profitably be built at many localities within the mountains. Also to a certain extent storm waters can be utilized by diverting them on the uplands and permitting them to spread over a larger area instead of allowing the run-off to escape rapidly in the natural channels. The effect would be an appreciable increase of the downstream seepage and of the replenishment of the underground store. Moreover, storm discharge may be lessened by planting trees and by protecting the watershed from fire, lumbering, and grazing, thereby promoting retention of the water by absorption and the increase of seepage run-off long after the storms are over. Another important loss of water occurs because of faulty methods of transportation for use in irrigation. As the need of economy increases more efficient conduits will replace crudely constructed ditches. Water thus saved, however, proportionally diminishes the replenishment of the underground store. Loss also occurs by allowing artesian wells to flow when the water is not needed. Either the wells should be capped or the flow at least be partly checked when water is not used, or it should be collected in reservoirs.

The abundance of water in the lowlands and a dearth of it in the uplands, where the soil is generally fertile, free from alkali, and well adapted to the growth of fruit, suggest that a more efficient application of the available water supply should be practiced. Because of the scarcity of the underground supply on the uplands and the possibility of distributing creek water there by high-level canals, and since there is not enough water in the creeks to directly serve both the uplands and lowlands, it would appear that steps should be taken to increase the upland supply from the creeks and to use wells, either flowing or pumped, in developing the lowlands. The popularity of pumping plants in irrigation elsewhere, the proximity of underground water to the surface in the lowlands, and the availability of electric power that can be developed in the adjacent canyons are facts favorable to the proposed change. Moreover, seepage from the greater use of creek water on the uplands will increase the available underground supply in the lowlands. The upland water supply may also be increased by the development of springs, by tunneling into the mountains, and possibly by the construction of subsurface dams and infiltration galleries at favorable localities.

More attention should be given to developing and preserving a pure water supply for domestic purposes. Surface streams should be protected from pollution, and care should be taken to reduce to a minimum the contamination of water in wells by using modern methods in the disposal of household refuse. The common location of the towns, near the base of the mountains, where sufficient amounts of pure water are generally available either from creeks or springs renders the problem of public water supply relatively simple; yet it is a remarkable fact that only a few towns utilize their opportunities.

OCCURRENCE OF UNDERGROUND WATER.

WEST OF JORDAN RIVER.

DIVISIONS OF AREA.

The area west of Jordan River within the region covered by this report is naturally divided into two parts. One is the lowland which extends from Great Salt Lake eastward to Jordan River and thence continues in a narrow belt southward, adjacent to the river; the other is the upland which, from the southern and western border of the lowland, extends with increasing elevation to the base of the Oquirrh Mountains. No sharp line of division can be drawn between these areas, for they grade into each other, yet on the whole they are distinct. The distribution of underground water in the two areas also is distinct, a convenient line of separation being that which marks the boundary between flowing and

nonflowing wells. As shown by Pl. VII, this line lies close to the Jordan in the southern part of its course, but across the river from Murray takes a westward turn, and, following the base of the upland, extends to Great Salt Lake at the northern base of the Oquirrh Mountains. This line also roughly marks the boundary between shallow and deep ground water. In the lowland area ground water is abundant and generally lies within 10 feet of the surface, while on the upland water is generally scarce and is found only at a depth of over 50 feet.

UPLAND AREA WEST OF JORDAN RIVER.

In general the upland has the aspect of a rolling plain which gradually rises to the base of the mountains, but in detail the plain is varied by the presence of benches and escarpments, relics of Lake Bonneville and of a few drainage ways that have incised channels across the plain. Locally, especially at the northern end of the Oquirrh Mountains and at the Narrows, where Jordan River flows through the Traverse Mountains, the shore lines of Lake Bonneville are unusually well marked. Different stages of the lake's history are recorded by a series of distinct benches, which descend one below another from the Bonneville level; at Jordan Narrows, for instance, no less than ten periods of pause in the lake level are thus recorded. Shore phenomena in general, however, are less prominently marked on the western margin of Jordan Valley than on the eastern, adjacent to the Wasatch Mountains.

Bingham Creek is the only perennially flowing stream which runs for any considerable extent across the plain, though Butterfield Creek flows for a short distance after it emerges from the mountains southwest of the town of Herriman. This area is also traversed by a number of arroyos which contain water only for a few days after storms and during the time of rapidly melting snow. The Utah and Salt Lake and the South Jordan canals, carrying water from the upper part of Jordan River, extend along the eastern border of the upland and supply irrigation water to a narrow belt. Above the upper canal the area is desert and practically uninhabited, except for the town of Herriman and a few scattering ranches which obtain local supplies of water. The Utah Lake project of the Reclamation Service plans to make available for irrigation a belt from 2 to 4 miles wide west of the Utah and Salt Lake canal, but a large part of this upland area west of Jordan River has too great an elevation to be cheaply irrigated from Jordan River. Some amelioration of the present arid conditions may be effected by constructing reservoirs at the base of the mountains, but the collecting area is small and no very extensive additions to the water supply are likely to be derived from this source. More or less dry farming is already practiced here. The land is fertile, is practically free from alkali, and because of its location would be very valuable if an adequate supply of water could be obtained. Unfortunately, so far as known, underground water conditions afford little prospect of a large supply from that source, though valuable quantities can locally be recovered.

This upland area is largely underlain by gravel and sand, and along the base of the mountains coarse gravel predominates. The material was derived from the disintegration of the adjacent highlands and mostly deposited offshore in the ancient lake. The constituents have been worked over and sorted during the different stages of the lake's history, both by wave action and by subaerial influences, so that the resulting material is heterogeneous both as to its composition and arrangement.

Drills have recorded only to a very limited extent the nature of the deposits that underlie the surface. Judging from the records and from conditions elsewhere, it is probable that bed rock lies not far from the surface contiguous to the base of the mountains, and that at a distance from the highland bed rock lies at a considerable, though unknown, depth. Nearer the mountains the unconsolidated valley filling is doubtless of coarser texture than farther away, and it is likely that the materials are arranged lenticularly rather than in continuous beds. That portion of the slight precipitation on the low, small watershed of the Oquirrh and Traverse mountains that is not evaporated or does not join the permanent run-off is absorbed by the porous deposits. Under the influence of gravity the water

penetrates downward until a relatively impervious layer is reached, when it tends to spread laterally and to slowly move toward a lower level, at the same time filling, to a greater or less extent, the voids in the overlying material.

In the greater part of the area occupied by Lake Bonneville bed rock is so deeply covered by valley deposits that it is impracticable to recover the water contained in it; but along the border of the old lake, where the rock outcrops, water is obtained from tunnels in a number of places. In the development of the Bingham mines more or less water has been encountered, and the town is supplied from mine tunnels. Water has also been found in two tunnels constructed for mining purposes near the base of the mountains. The Butterfield tunnel, in Butterfield Canyon, a few miles west of Herriman, encountered considerable water, which has caused some litigation. After the construction of the tunnel a number of springs tributary to Butterfield Creek ceased to flow, and suit was brought against the mining company by the inhabitants of Herriman. Apparently the source of the springs was tapped by the tunnel, and judgment was awarded against the mining company. The Dalton and Lark tunnel, west of the town of Lark, struck water in the spring of 1903. The tunnel was driven 5,000 feet through igneous rock before the water was found. It occurs in quartzite that is reported to be much broken and fissured. The supply was estimated at first to be 2,500 gallons a minute, but in the summer of 1904 this had decreased to about 1,500 gallons, most of which was used for irrigation at a ranch about 2 miles east of the mouth of the tunnel. The quantity is reported to be greatest shortly after the time of melting snow, thus indicating the source. The experience of these tunnels indicates in general what may be expected by driving into the Oquirrh Range.

Springs of greater or less magnitude occur in a number of places along the base of the mountains. These are either supplied by seepage or by water from a deeper-seated source. In Rose, Butterfield, and Bingham canyons a number of springs occur, which help maintain the flow of the streams. Also at irregular intervals along the border of the upland there are springs which, in general, supply only a few gallons a minute. A conspicuous locality is in the northwestern part of T. 2 N., R. 2 W., where a local area of shallow ground water occurs. Along the northern base of the Oquirrh Range there is a group of large springs, which occur in notable alignment and apparently are associated with a fault. The water issues from unconsolidated débris and is slightly warm and brackish. The springs have an elevation of only a few feet above the lake, however, and are too low to be of much service without pumping. Analysis of one, known as the Jap Pond, shows a content of 114 grains per gallon of dissolved salts, chiefly sodium chloride. The total discharge of 9 of these springs in April, 1905, amounted to 8.5 second-feet, and it is reported that the flow remains practically constant throughout the year.

On the upland, between the base of the mountains and the canals, the little underground water that is recovered is obtained from wells, but in this entire region, with very few exceptions, ground water lies over 50 feet beneath the surface. A few wells have been sunk on the upland away from the lines of surface drainage, and in general they have been failures. The most successful wells are along the courses of creeks and arroyos, and future search may be carried on with the best prospect by following these drainage ways where the water tends to accumulate.

Development in Bingham Canyon illustrates the occurrence of underground water beneath a surface-drainage way. More or less placer mining has been carried on in the creek gravels, but near the mouth of the canyon, where there is a considerable amount of débris, work has been seriously interrupted by the abundance of water beneath the bed of the creek. It is in such places, where rock walls confine a narrow channel, that tests might well be made with the view of constructing subsurface dams to impound the underflow.

Below the canals ground water lies nearer the surface, because of the lower elevation of the country and the increased supply derived by seepage from the canals. Ground water lies at a greater depth than 50 feet only in a narrow belt below the Utah and Salt Lake Canal, and in most of the area between the canals and the line of flowing wells ground water

can be obtained at 10 to 50 feet from the surface. The effect of irrigation on ground water in this area, as elsewhere, is marked. Before irrigation was practiced the depth to water was considerably greater than at present; for instance, it is reported that the average level of ground water in several wells in T. 2 S., R. 1 W., now lies 30 to 65 feet nearer the surface than formerly. Besides this more permanent effect, the ground-water level fluctuates annually from 10 to 15 feet. It is also stated that the quality of ground water has deteriorated in recent years, containing now much more alkali than formerly. So marked has this change been that surface wells are but little valued, and generally water for domestic use is obtained from deep wells.

Inspection of the list of wells will show the typical facts of distribution and occurrence of underground water in this region. It will be observed that many wells are about 250 feet deep and that the range is from less than 100 feet to 1,000 feet. No careful logs have been kept, but from fragmentary information it appears that there is considerable variation in the material encountered in drilling, implying that the sediments are irregularly sorted and that they exist in more or less lenticular arrangement. Accordingly there are no persistent water horizons. Water is generally found in wells wherever sand and gravel are encountered. In several wells a number of water beds are recorded. This water is always under pressure; the height to which it rises varies, according to location and elevation, from close to the surface down to 100 feet below it. Generally, fairly good water, within easy pumping distance, is obtainable in this belt of country between the canals and the line of flowing wells.

At the Cannon farm, in sec. 34, T. 2 S., R. 1 W., a well was sunk 1,000 feet in an attempt to get a flow, but although two thin water-bearing beds were found between 600 and 800 feet, from which the water rose to within 30 feet of the surface, flowing water was not obtained.

LOWLAND AREA WEST OF JORDAN RIVER.

The lowland that lies topographically below the line of flowing wells west of Jordan River is almost a level plain which, along its margin, rises gradually toward the southwest. Local depressions in the plain are occupied by shallow alkaline lakes, which formerly had no outlet but now are drained into Jordan River. The soils of the lowland are chiefly loam and sandy loam, but adjacent to the lake and in local low areas considerable clay is present.[a]

The nature of the underlying deposits is revealed by a number of well records, and (as would be expected) fine-textured materials are more abundant than nearer the mountains. A few deep wells have been sunk in this general region, proving the great thickness of the old lake deposits. The deepest is the Guffey-Galey well, drilled near the shore of the lake, 2 miles southwest of Farmington and about 10 miles north of Salt Lake City, in an unsuccessful search for oil.[b] This well was put down 2,000 feet without encountering bed rock. Another deep well is that of the Rio Grande Western Railway at Salt Lake City, which was sunk through alternating beds of sand and clay, with very little gravel, to a depth of 1,073 feet. This is the deepest well in the area under consideration, and its record (p. 42), as given by the driver, Gus Westphal, is as follows:

[a] A soil survey in Salt Lake Valley: Bull. U. S. Dept. of Agriculture No 64, 1900.

[b] Boutwell, J. M., Oil and asphalt prospects in Salt Lake basin: Bull. U. S. Geol. Survey No. 260, p. 471.

Record of Rio Grande Western Railway Company's well at Salt Lake City.

	Thickness in feet.	Depth in feet.
Thin strata of clay and sand	130	1–130
Clay and hardpan	40	130–170
Red sand	30	170–200
Clay and hardpan	60	200–260
Gray sand	5	260–265
Clay and sand	44	265–309
Sand	8	309–317
Clay	20	317–337
Sand	13	337–350
Hard clay	6	350–356
Sand	8	356–364
Clay	10	364–374
Sand	18	374–392
Clay	20	392–412
Sand	4	412–416
Clay	10	416–426
Blue sand	12	426–438
Clay	5	438–443
Blue sand	30	443–473
Hard clay	10	473–483
Sand and gravel	1	483–484
Clay	12	484–496
Gravel	4	496–500
Gray sandy clay	28	500–528
Tough blue clay	30	528–558
Hardpan	3	558–561
Sand	8	561–569
Soft blue clay	40	569–609
Sandy blue clay	40	609–649
Hardpan	2	649–651
Sand	16	651–667
Sandy gray clay	18	667–685
Red sand	36	685–721
Gravel	10	721–731
Blue clay	76	731–807
Clay and sand, alternating every 12 or 18 inches	84	807–891
Hardpan	8	891–899
Sand and gravel	11	899–910
Blue clay	16	910–926
Gray clay	24	926–950
Sandy gray clay	13	950–963
Quick sand	15	963–978
Blue clay	21	978–999
Sandy blue clay	11	999–1,010
Quicksand	10	1,010–1,020
Gray clay	11	1,020–1,031
Fine blue sand	3	1,031–1,034
Tough blue clay	12	1,034–1,046
Hardpan	2	1,046–1,048
Fine sand	21	1,048–1,069
Hard blue clay	4	1,069–1,073

Although the general composition of the old lake deposits is known, not enough information has been accumulated to enable very definite statements to be made concerning the detailed distribution of the sediments. A comparison of available well records shows that the alternating beds of sand, clay, and gravel, generally, can not be recognized as being equivalent in the several wells, and from the present evidence it appears that while there are great thicknesses of both sand and clay, which must have a more considerable lateral extent than the beds nearer the mountains, the lake deposits are lenticularly arranged. Since no correlation has been established, the structure of the lake deposits is not known. Apparently they are approximately horizontal, but with a slight inclination toward the lake from the highlands. This is indicated by the pressure obtained in artesian wells and is proved in a few instances by well records.

In the broad lowland west of Jordan River there is an abundance of water. Throughout practially all of this area ground water lies within 10 feet of the surface, and water is contained in the underlying deposits down to an unknown but considerable depth. Apparently flowing wells can be obtained anywhere within this area. Although the water is so generally distributed, it is profitably recovered only from the more porous, coarser textured deposits of sand and gravel, which constitute natural reservoirs and in which the water moves more readily. Accordingly, water is found at several horizons in the course of sinking a deep well. In the Rudy well, for instance, 1,002 feet deep, situated in sec. 5, T. 1 N., R. 1 W., 25 water horizons from which surface flows were obtained are reported. A record of this well is not available, but "good strong" flows besides minor ones were recorded, respectively, at 400, 508, 685, 753, and 881 feet.

Though water is so abundant, this lowland region is thinly populated, the chief drawback to its settlement being the presence of much alkali in the soil over a considerable part of

the area. The Bureau of Soils of the United States Department of Agriculture, in cooperation with the Utah Experiment Station, is at present engaged in a demonstration of the feasibility of reclaiming this land on a farm 3 miles west of Salt Lake City. But by no means all of the soils in this lowland area contain excessive amounts of alkali,[a] especially along Jordan River and adjacent to the border between the lowland and highland areas there are thriving settlements.

The map and list of wells show general conditions. The wells are grouped along the margins of the area, and few are located in the interior. In general they are 2 inches in diameter, but they vary in depth greatly. Although flows are obtained locally at only 30 feet below the surface, commonly they are not encountered above 150 feet. Perhaps the average well is between 200 and 300 feet in depth. It is a striking fact that flows may be obtained throughout the entire area at similar, but not at regular depths, indicating only a slight inclination of the water-bearing horizons and their lenticular character. The flows are usually small, averaging perhaps under 5 gallons a minute, though there are a number of 15-gallon flows. The supply generally is reported rather constant, except that the shallower wells are subject to seasonal variation. The pressure obtained, too, generally is small, being only enough to cause the water to rise either barely to the surface or a few feet above. In general the pressure and the flow are reported to increase with the depth but measurements are not available. Both the flow and the pressure are considerable in the deep Rudy well, sec. 5, T. 1 N., R. 1 W.

The conditions here noted apply mostly to the areas contiguous to the eastern and southern borders of the lowland west of Jordan River. Little information is available concerning the rest of this area (see list of wells pp. 59–75.) The few wells near Great Salt Lake were sunk to unusual depths before flowing water was obtained, this being apparently due to the greater development of clay in that region, though no complete logs have been kept. The well at the Inland Crystal Salt Company's works, in which, at a depth of 560 feet, water was struck which rises about 9 feet above the surface and flows about 10 gallons a minute, is reported 720 feet deep. Underground water in the Pleistocene deposits near the lake contains considerable salt.

EAST OF JORDAN RIVER.

East of Jordan River the occurrence of underground water will be described under the following heads: Salt Lake City, lowland area south of Salt Lake City, and upland area south of Salt Lake City.

SALT LAKE CITY.

Salt Lake City is built principally on the floor of the main valley, but its outskirts extend northward on the old delta of City Creek and eastward on the benches at the base of the Wasatch Mountains. Adjacent to the highlands the underlying deposits are very irregular in composition and distribution, consisting of sand and gravel with intercalated streaks of clay. But toward the valley proper the conditions become more regular and the prevailing clay is interbedded with sand and gravel, though from the records obtained no definite sequence appears to be applicable to any considerable area.

In the lower part of the city marshy areas occur, but conditions there have been much improved since the early days of settlement. Formerly the lower channels of City, Red Butte, Emigration, and Parleys creeks were ill defined and at high-water stage the part of the city adjacent to Jordan River was a great slough. But by erecting embankments, by confining the creeks to definite channels, and by draining the western part of the city much of the swampy land has been reclaimed. Shallow ground water, except on the benches, generally lies within 10 feet of the surface.

The line separating flowing and nonflowing wells skirts the lower benches, so that in the larger part of the area occupied by the city artesian wells are obtained. Flows are found

[a] Soil survey in Salt Lake Valley: Bull. U. S. Dept. Agric. No. 64, 1900. Reclamation of Alkali ands: Fifth Rept. Bureau of Soils, 1903, p. 1144.

at different horizons from about 50 feet downward, a common depth of wells being between 100 and 300 feet. The deepest well is that of the Rio Grande Western Railway Company near its station, the record of which appears on page 42. This well is 4 inches in diameter and 1,073 feet deep. It was put down in 1895 and 15 horizons were passed through from which flows were obtained. At a depth of 1,048 feet the greatest flow occurred, amounting to 78 gallons a minute at 4 feet above the surface and to 37.5 gallons at 25 feet above.

The most notable group of wells in this vicinity is that put down by Salt Lake City adjoining Liberty Park. There are 16 or more of these ranging from 2 to 9 inches in diameter and from 100 to 600 feet in depth. About half a dozen different water-bearing horizons, each furnishing a flow, are said to have been encountered in driving the wells. The greatest pressure reported caused the water to rise in a pipe 35 feet above the surface. Discharge measurements, as furnished by the city engineer, are given in the following table:

Discharge of city wells near Liberty Park, Salt Lake City.

No. of well.	Diameter.	Date of measurement.			No. of well.	Diameter.	Date of measurement.		
		Aug. 10, 1890.	July 17, 1900.	Sept. 29, 1902.			Aug. 10, 1890.	July 17, 1900.	Sept. 29, 1902.
	Inches.	*Gallons.*	*Gallons.*	*Gallons.*		*Inches.*	*Gallons.*	*Gallons.*	*Gallons.*
1....	9	201,600	120,000	96,941	10....	2	43,200	38,000	35,644
2....	9	180,000	297,000	60,588	11....	2	33,230	19,000	15,892
3....	8	279,132	280,000	302,940	12....	2	36,000	16,000	14,213
4....	8	....	215,000	193,882	13....	2	54,000	35,000	20,626
5....	8	59,040	5,000	11,459	14....	2	....	18,000	13,316
6....	2	14,400	10,000	5,876	15....	9	....	98,000	36,172
7....	2	16,000	1,000	610	16....	2	....	6,000	2,844
8....	2	27,000	500	206					
9....	2	54,000	25,000	19,784			997,602	1,183,500	830,993

In the immediate vicinity of these wells there are a number of springs whose supply is maintained chiefly by seepage. The combined flow from these springs and wells is estimated to amount to a maximum of 2,500,000 gallons a day. In order to utilize this supply in the city mains a pumping plant would have to be installed, and a further disadvantage is the doubtful quality of the water. At present this source is used for street sprinkling and for feeding the lake in Liberty Park (Pl. I).

In the northern part of Salt Lake City several thermal springs occur, the most conspicuous of which are the hot and warm springs. The hot springs issue at a temperature of about 130° from the Wasatch limestone at the western end of the spur of the mountains, with a discharge of about three-fourths second-foot,[a] and flow into Hot Springs Lake. The warm springs issue from unconsolidated deposits at the base of the spur about 2 miles southeast of the hot springs. The water is pumped to a slight elevation, from which it is piped to a sanitarium, the amount delivered being reported to average 350 gallons a minute. The temperature is 118° at the springs and about 100° at the sanitarium. Several other similar, but less important, springs occur, associated with the great Wasatch fault, along the base of the mountains between hot and warm springs.

The municipal water supply of Salt Lake City is derived from mountain streams and distributed through city mains. From this source there is an excellent supply of pure water under good pressure. The chief near-by available streams are City, Red Butte, Emigration, Parleys, Mill, Big Cottonwood, and Little Cottonwood creeks. The discharges of some of these are given on pages 19-22. None of these except City Creek is entirely controlled by the city. Red Butte Creek is reserved for the army post at Fort Douglas, Emigration and Parleys creeks partly contribute to the city supply, and the others are used entirely for

[a] Measured by A. F. Doremus.

irrigation and domestic purposes, under water rights owned by farmers. In order for Salt Lake City to utilize these streams it must buy the water rights or exchange with the farmers an equivalent amount of water obtained either from Utah Lake or from pumping plants.

The present public supply accordingly is obtained from City, Parleys, and Emigration creeks. The watershed of City Creek is protected from forest fires and from contamination, and many of its springs are developed. The flow is distributed from settling tanks near the mouth of the canyon and from a reservoir on Capitol Hill having a capacity of approximately 1,000,000 gallons. The surplus waters of City Creek are allowed to escape through flood ditches. Water from Parleys Creek to the extent of 81.8 per cent of its flow has been obtained by Salt Lake City in exchange for an equivalent amount of water from Utah Lake delivered through the Jordan and Salt Lake City canal. A settling reservoir, holding somewhat less than 1,000,000 gallons has been constructed at the mouth of Parleys Canyon, whence the water is conducted through a concrete conduit to a storage reservoir with a capacity of about 5,000,000 gallons situated on Thirteenth East street. An additional supply is obtained from a trench in the bed of Emigration Creek half a mile above the mouth of the canyon. This trench is approximately 150 feet long, 10 feet wide, and 18 feet deep. It was dug in sand and gravel in the bed of the creek and at right angles to its course. A supply estimated to amount to 1,000,000 gallons a day is thus obtained, which is piped to the Thirteenth East street reservoir.

No direct record is kept of the amount of water used by Salt Lake City, but discharge measurements of the creeks at the mouths of the canyons show the amount available. This is insufficient during the dry months and the use of water is restricted to a per capita consumption of 120 gallons a day, although it is considered desirable, in this dry climate, where lawns and gardens have to be irrigated, to maintain a per capita supply of approximately 300 gallons a day. It is planned to obtain in the immediate future a portion of the flow of Big Cottonwood Creek, by exchanging therefor water from Jordan River, delivered through the City canal, as is being done in the case of Parleys Creek, and to make the new supply available by constructing a pipe line from the mouth of Big Cottonwood Canyon to the mouth of Parleys Canyon, a distance of about 7 miles.

SOUTH OF SALT LAKE CITY.

Lowland area.—It will be convenient to divide the area south of Salt Lake City into a lowland and an upland portion, taking as the dividing line that which separates flowing and nonflowing wells. Pl. VIII shows that this line extends contiguous to, but below, the Jordan and Salt Lake City canal as far as Little Cottonwood Creek, after crossing which it turns westward to the flood plain of Jordan River. The lowland area is traversed by Parleys, Mill, Big Cottonwood, and Little Cottonwood creeks, which flow in open valleys, with broad and low intervening divides. The general aspect of the country is that of a slightly dissected plain that rises gently toward the upland terraces. This area is relatively thickly populated, and intensive farming is widely practiced.

The detailed character of the underlying lake sediments is not satisfactorily known, but from the well records conditions appear to be similar to those found elsewhere in the area under consideration. Beneath the lowlands the stratigraphy is more uniform than nearer the base of the mountains; fine-textured sediments are more abundant than coarse, and clay predominates. But a comparison of available well records fails to establish a correlation between the different beds of sand and gravel throughout the lowland. Well drivers state that all logs are different, and yet that, on the whole, general sections persist for certain areas in which the differences are minor. It is believed that the sediments slope toward Jordan River at about the same angle as does the surface. The best-defined sequence that has been reported occurs immediately south of Salt Lake City, where in general light-colored clay at the surface overlies blue clay ranging from 30 to 70 feet in thickness, beneath which water-bearing sands and gravels occur at a depth of about 100

feet. At greater depths the succession appears to be more variable, but there are few satisfactory well records.

Ground water now lies within 10 feet of the surface over practically the entire lowland area, but it is reported that in the early days it did not lie so near over so large an area. Present conditions are largely due to irrigation. Several old residents state that below the level of the Jordan River canals the ground-water surface has locally risen 40 or 50 feet since their construction. It has already been mentioned that along several of the drainage ways seepage water reappears at the surface and occasionally forms considerable streams, as at Spring Creek near its junction with Big Cottonwood Creek, where the September flow is estimated to amount to 14,000,000 gallons a day. In many places also, especially along the bases of benches, lines of seep springs occur that furnish considerable flows, a notable occurrence being those at the nursery in the southeastern part of Salt Lake City. But locally, as along the bluff east of Jordan River, north of the Bingham Junction smelters, the water appears at so low an elevation as to be of comparatively little use. When pumping becomes more generally practiced in the valley this ground water that lies so near the surface can be easily developed.

Flowing wells in this area are numerous. They are generally 2 inches in diameter and 100 to 400 feet in depth, and they commonly yield between 20 and 50 gallons a minute, though there are many variations. The pressure is low, generally less than 10 pounds. Well drivers say that their best results are obtained in belts extending northwest and southeast, parallel with the creeks, and that these productive belts are separated by relatively barren ones. The water-bearing sands and gravels apparently mark the courses of old waterways, while finer-textured material was deposited in the intervening areas These distinctions have been noticed only in the upper parts of the lowland area, and near the river they are said to disappear. One of the best wells is at the plant of the American Smelting and Refining Company at Murray. It is 4 inches in diameter, 400 feet deep, and is reported to flow about 400 gallons a minute under a pressure of 3 pounds per square inch. The record of this well is given as follows, on the authority of H. F. Yeager, well driller:

Record of American Smelting and Refining Company's well at Murray.

	Thickness in feet.	Depth in feet.
Sand and gravel	5	0-5
Mud	3	5-8
Sand and gravel	4	8-12
Blue clay	6	12-18
Quicksand	10	18-28
Blue clay	8	28-36
Loose sand and gravel (good pump well at 42 feet)	16	36-52
Blue clay	8	52-60
Quicksand (flow at 63 feet)	6	60-66
Blue clay	18	66-84
Yellow clay	6	84-90
Loose sand and gravel (strong flow at 95 feet)	15	90-105
Yellow clay	3	105-108
Coarse gravel and rock (strong flow at 112 feet, and at this point the well at office stopped flowing)	8	108-116
Coarse gravel and rock	6	116-122
Quicksand	20	122-142
Clay, very hard	10	142-152
Quicksand	6	152-158
Gravel (small flow at 165 feet)	11	158-169
Hard pan, very hard	8	169-177
Blue clay	6	177-183
Quicksand (flow at 203 feet)	20	183-203
Quicksand	16	203-219
Blue clay	4	219-223
Quicksand	7	223-230
Blue clay	8	230-238
Quicksand	18	238-256
Blue clay and quicksand in layers 2 feet thick	22	256-278
Quicksand	8	278-286
Blue clay, very hard	12	286-298
River sand	2	298-300
River sand	7	300-307
Cemented gravel	12	307-319
Yellow clay	7	319-326
Cemented gravel	17	326-343
Loose gravel	23	343-366
Yellow clay	2	366-368
Gravel	7	368-375
Cemented gravel	12	375-387
Loose gravel	12	387-399

Decrease in flow and complete failure of some wells are reported throughout this area and are especially apparent in the vicinity of Murray. These results are directly traceable to the increased number of wells that have been sunk in recent years and to the fact that little economy is exercised in the use of the water. Well owners should more fully realize that the limited water supply comes from a common source, that the wastefulness of one counteracts the prudence of another, and that the common interest of all demands that the supply be conserved.

Upland area.—The upland south of Salt Lake City includes the area lying between the base of the Wasatch and Traverse mountains and the area in which flowing wells can be obtained. This region is characterized topographically by the abundance and perfection of development of shore phenomena which mark different stages in the history of Lake Bonneville. As on the western side of the valley, the upland is in general a plain that rises toward the base of the mountains, but is interrupted by benches and escarpments and deeply cut by the creeks flowing from the Wasatch Mountains.

The Bonneville terrace extends along the mountains like a narrow shelf, its horizontal lines contrasting strongly with the deep, vertical furrows on the mountains. Broad deltas formed by the larger creeks at the Provo stage extend down to the lowlands, and successive escarpments mark halting places in the retreat of Lake Bonneville. The most prominent of all the shore phenomena in the area covered by this report is the great embankment at the point of the mountains east of Jordan Narrows. Here the waves, gaining energy from the wide expanse of the old lake, carved a great sea cliff against the mountains and distributed the débris to form an enormous accumulation of sand and gravel.

Prominent local features of this upland belt are the relics of glaciers adjacent to the mouth of Little Cottonwood Canyon and the evidences of recent faulting along the base of the mountains. Little Cottonwood Creek in Pleistocene time was occupied by a glacier which carved a broad U-shaped valley and deposited lateral and terminal moraines composed of a heterogeneous mass of coarse- and fine-textured débris. Along the entire front of the Wasatch Mountains Gilbert has found indications of recent dislocation associated with the great Wasatch fault. The evidence is varied, but escarpments in unconsolidated material breaking the even trend of alluvial slopes are conspicuous.

The underlying deposits of the upland are mostly coarse textured, being near their origin, and consist chiefly of sand and gravel. The creeks, where they have cut deeply, expose good sections, but few deep-well records were obtained.

This region in general is thinly populated, but where water is available there are settlements, and wherever the canals extend there are thriving farms. The contrast between the flourishing area which is supplied with water and the dry, barren region is striking. The map shows the distribution of the principal canal systems, which are supplied by the several creeks that flow from the Wasatch Mountains and by Jordan River. Underground water is used only to a limited extent. Pl. VI and the list of wells illustrate conditions. Underground water is recovered chiefly in the lower (western) part of the upland, where it lies at depths ranging from the surface to 50 feet below. In this productive area both dug and driven wells are used. The driven wells are commonly 50 to 200 feet in depth, and water is generally found beneath a bed of clay in sand or gravel under sufficient pressure to cause it to rise within pumping distance of the surface.

In the eastern part of the upland area ground water generally lies at a greater depth than 50 feet below the surface, and in a number of places has not been found in test wells over 100 feet deep. In this (eastern) division of the upland, where the greater part of the valley deposits are coarse textured, the ground water sinks deep before a relatively impervious bed is encountered, and then it tends to move to the lower part of the valley. Away from the influence of seepage from the creeks little water is supplied to this area. Between the creeks the chief source of supply is seepage from the mountains. The most likely localities for sinking wells are along the courses of waterways, but over a large part of the upland the prospect is poor for obtaining underground water in quantity within easy reach of the surface. In the mouths of the canyons there is the chance of developing the underflow by

subsurface dams or by tunnels, mentioned on page 40. Other favorable localities for prospecting are adjacent to the base of the mountains, where water may be had by developing springs and by tunneling into the bed rock.

Seep springs occur at several localities along the base of the mountains south of Salt Lake City, the most important, perhaps, being those about midway between Mill and Big Cottonwood canyons. The feeble springs there issuing from sand and gravel were formerly allowed to go to waste, but by developing them a flow of about 2 second-feet was obtained, and a considerable tract of land thus became available for agriculture. About 4 miles southwest of the town of Draper, in sec. 12, T. 4 S., R. 1 W., at some distance from the base of the mountains, there are four warm-water lakes that are fed by springs, some of which are said to be quite hot. The westernmost of the group is the largest and covers an area of about 5 acres. The temperature is reported to remain at about 70° the year round.

Since underground water is so scarce beneath the upland, the most efficient manner of developing this area appears to be by the use, as suggested above (p. 38), of creek water in high-level canals to a greater extent than is now practiced.

UTAH LAKE VALLEY.

The following description of the occurrence of underground water in the valley of Utah Lake begins at the north and proceeds east, south, and west around the lake, the several towns affording subheadings for convenient reference. (Pl. VIII.)

LEHI AND VICINITY.

Lehi is situated in the main valley at some distance from the distinct terraces. Dry Creek lies adjacent to the town, but, as its name signifies, the creek, after supplying a number of irrigation ditches, usually carries little or no water in its lower course. There is no public water system in the town, and the supply for domestic purposes is derived from numerous wells. A few shallow dug wells tap ground water at depths of 5 to 30 feet, but the majority are deeper and reach water under pressure. The sugar-plant mill pond is fed by springs and is an important local source of supply.

Lehi was one of the first towns where artesian water was found in the Bonneville area, flowing wells having been obtained there about 1880. Formerly a feeble first flow was found in gravel about 60 feet from the surface and a stronger supply at a depth of about 160 feet, but in recent years flows, even from the second horizon, have failed during part of the season in consequence of the increased use of artesian wells in the area nearer the lake, and at times pumping has to be resorted to. However, when water does not actually flow it rises in the wells to within a few feet of the surface.

The general section in the vicinity of Lehi, as reported by H. C. Comer, shows blue clay to a depth of 50 or 60 feet. Below this is the first water bed, consisting of about 50 feet of sand and gravel, separated from the second water horizon by 40 feet of light clay. This section does not apply in the eastern part of the town, where the log of the San Pedro Railroad well shows coarse-textured material within 100 feet of the surface. In this well the main supply is derived from a depth of 330 feet, the water rising to within a few feet of the surface. These two logs illustrate the variability of adjacent sections.

The Utah Sugar Company's plant at Lehi has several 2-inch wells, and the following flows in gallons per minute are reported: 80 feet, 15 gallons; 120 feet, 25 gallons; 150 feet, 20 gallons. Logs of these wells were not kept. The Rio Grande Western Railway well near the sugar factory is 3 inches in diameter and 165 feet deep. The water is reported to rise in a pipe to a point 30 feet above the surface and to flow about 50 gallons a minute at the level of the ground.

Toward Utah Lake, below Lehi, there is a considerable development of flowing wells from which a number of square miles are irrigated. In this district there are several hundred flowing wells which average about 150 feet in depth. A close relationship has been established between the flow of the wells in the fields below Lehi and those in town.

During the irrigation season, when the field wells are all flowing, those in Lehi practically stop, but during the winter it is a general custom to plug the wells used for irrigation, after which those in town begin to flow. Measurements have not been made, but the general facts are well established.

Northwest of Lehi the line separating the areas of flowing and nonflowing wells continues to Jordan River, reaching it 3 to 4 miles north of Utah Lake. The line extends about half a mile west of the river and approaches close to the northwest corner of the lake near Saratoga Springs. In the flood plain of Jordan River flows can probably be obtained continuing into Salt Lake Valley, but outside of the line indicated the surface elevation is too great.

The Salt Lake City authorities, about 1890, sank a number of wells in the flood plain of Jordan River in sec. 12, T. 5 S., R. 1 W., with the object of increasing the supply of the Jordan and Salt Lake Canal. These wells, about 130 in number, were mostly 2 inches in diameter, though a few were 6 inches, and are said to average 100 feet deep. Clay was encountered down to the bottom of the wells, which were in gravel. It is stated that water rose in pipes 30 to 40 feet above the surface, and that individual wells flowed 125 gallons a minute. It is also stated that the combined flow amounted to 3,000,000 gallons a day. These wells soon interfered with neighboring ones, stopping their flow, and suit was brought against the city, with the result that the municipality was compelled to plug up its wells. After these had been plugged for some time a number of them were temporarily opened, and in about twenty-four hours thereafter the water in one of the wells, the flow of which was interfered with, situated about half a mile above the city wells, had fallen 2½ feet. The city wells were then capped again and in five hours the water in the well referred to had regained 7 inches of its lost level.

Near the northwestern end of Utah Lake there is a group of hot springs which occur both on shore and in the lake. On the shore there are several springs which support the Saratoga resort where the water, having a temperature of 111°, issues through the lake deposits and is used for bathing and to a limited extent for irrigation. In the summer of 1904, during the survey of Utah Lake by G. L. Swendsen of the Reclamation Service, three groups of springs were found beneath the water of the lake. Their existence was shown by the presence of depressions occupying areas of 100 square feet to 3 acres in extent and having depths of 20 to 80 feet. Since the prevailing depth of the lake is much less and the bottom is composed of slimy mud, a considerable discharge is thus indicated. Hot water that flowed above the lake surface was obtained by sinking pipes a short distance into the bottom.

About 5 miles up Dry Creek from Lehi is the town of Alpine, located near the mouth of the canyon on the dissected Bonneville terrace. The settlement is supplied with water from irrigation ditches, and possibly not more than half a dozen wells have been sunk. These are 25 to 80 feet deep, and the water level is reported to vary considerably between winter and summer. Springs occur in Dry Creek Canyon, but they have not been developed.

AMERICAN FORK, PLEASANT GROVE, AND VICINITY.

The towns of American Fork and Pleasant Grove receive their main water supplies, respectively, from American Fork and from Battle and Grove creeks. These streams feed a number of irrigation canals, and are the chief source of underground water in this vicinity. (Pl. IX, *B*.)

American Fork is built at the base of a series of terraces on both sides of American Fork (creek), which has cut a narrow channel through the old lake deposits. Ascending the valley from American Fork, five distinct terraces can be traced up to the broad Provo bench, between which and the Bonneville level, which forms a shelving bench against the mountains, traces of shore lines of pre-Bonneville age have been reported. In its lower course American Fork is dry throughout most of the year in consequence of the draft upon its waters for the canal system which supplies the uplands.

Shallow wells in American Fork are commonly less than 50 feet in depth, averaging possibly 25 to 30 feet, and the ground-water level is reported to vary 10 to 15 feet between the winter minimum and summer maximum. The water generally is found in gravel.

Deep wells have been sunk in the extreme southwestern part of the town in search of flowing water. The water rises in these nearly to the surface, and furnishes the main supply for domestic purposes. Well records show a variable succession of sand and gravel, with comparatively little clay. The city well is typical, and probably is the deepest in this vicinity. It is 440 feet deep and 6 inches in diameter. Two principal water horizons are reported, at 240 and 340 feet, and the water stands in the well at a depth of 22 feet. An electric motor pump supplies water for public purposes, but there is no waterworks system. Individual families or groups of families maintain their own wells.

The line separating the areas of flowing and nonflowing wells as mapped between Lehi and Pleasant Grove lies contiguous to the San Pedro Railroad, and here, as elsewhere, ground water commonly lies within 10 feet of the surface. Extensive areas of marshy land lie contiguous to the lake shore, where conditions have grown worse since the introduction of irrigation. The flowing wells in this vicinity vary in depth, but are commonly about 100 feet deep. As Utah Lake is approached more nearly uniform conditions are revealed by the logs. Clay is commonly present at the surface and continues to a depth of 90 or 100 feet, below which the water-bearing gravel occurs. In the deeper wells alternating sand, clay, and gravel are reported below the first gravel, and flows are obtained from every coarse-textured bed. One of the best wells in this vicinity is in sec. 23, T. 5 S., R. 1 E. It is 147 feet deep, 2 inches in diameter, and throws a stream 3 feet 8 inches above the pipe, having a capacity, therefore, of about 150 gallons a minute.

A disturbed belt of rocks, dipping eastward, and locally covered by débris, lies near the foot of the Bonneville terrace between American Fork and Grove creeks. Springs occur at about this horizon, and prospecting for water in this belt, in sec. 17, T. 5 S., R. 2 E., has brought notable results. William Wadley & Sons, by tunneling into bed rock, have developed enough water to irrigate a number of acres of fruit land, which is bringing in handsome returns. Several tunnels have been dug, the most important of which lies about 200 feet below the Bonneville level and was driven 318 feet through black shale into broken and cavernous gray limestone, in which the water occurs.

Pleasant Grove is located on alluvial slopes formed by Battle and Grove creeks. Its situation is so high that flowing wells can be obtained only in the extreme lower part of the town, which depends for its chief underground supply on wells from which water has to be pumped. Ground water can usually be obtained at 10 to 50 feet from the surface. No regular sequence of deposits underlies the town, but a variable succession of clay, sand, and gravel is encountered in wells, the water horizon usually being underlain by clay. In the southeastern part of Pleasant Grove no successful wells have yet been obtained, though prospecting for them has extended to a depth of 100 feet; not deep enough to find an impervious stratum. A continuous succession of gravel beds is reported.

The high, almost flat Provo delta between Pleasant Grove and Provo is scantily provided with water. The surface is generally gravel covered, and gravel is commonly found in wells to depths of 30 to 60 feet, below which sand is reported. Only a small amount of clay appears to be present. This tract of land is well adapted for the cultivation of fruit, but the present supply of water is insufficient for its complete development. Water was first brought to the delta by canals from Provo River in 1868, and the present supply, whereby a maximum diversion of about 116 second-feet is obtained, was established in 1888. Before irrigation was practiced on the bench the depth to ground water was considerably greater than it is now. Old wells are over 100 feet deep, but of late years the ground-water surface has risen so that on a large part of the area water can be obtained in wells averaging 50 to 75 feet deep. Toward the lower margins of the bench the depths to ground water is less than 50 feet. Here, as elsewhere throughout this entire area, ground water is lowest in the winter and highest during the irrigation season. The annual variation on Provo bench appears to range from 5 to about 17 feet. A few examples will illustrate general conditions. In 1875 a dry well 100 feet deep was dug in sec. 14, T. 6 S., R. 2 E. In the same section, during the winter of 1878-79, N. Knight dug a well 110 feet deep which afforded 3 feet of water in winter and 15 to 20 feet in summer. In 1899 N. J. Knight

A. VALLEY OF PROVO RIVER BELOW MOUTH OF CANYON, LOOKING NORTH.

Shows Provo Bench and Bonneville terrace.

B. AMERICAN FORK AT MOUTH OF CANYON.

dug a third well only 60 feet deep, near the second, which afforded about 3 feet of water in winter and 20 in summer.[a]

Flowing wells can not be obtained on the bench because of its elevation, though several attempts have been made, without success. In 1887 and 1888 two deep wells were driven in the same section as those just referred to. The Colorado Fish Company put down a 3-inch well 250 feet deep and obtained water which rose to within 80 feet of the surface. This was pumped for several years. In 1888 Mr. Knight drove a 2-inch well 300 feet deep in which water rose to within 90 feet of the surface. Both of these wells are now abandoned.

From Provo to Pleasant Grove along the narrow belt of lowland lying between Provo bench and Utah Lake there is an abundance of underground water. The line that separates flowing and nonflowing wells coincides approximately with the San Pedro Railway, which also marks roughly the upper limit of the area in which ground water lies within 10 feet of the surface. Between the railroad and the base of the bench few wells have been driven and little is known of the conditions, but it is thought that water can be obtained at depths of 10 to 50 feet.

Contiguous to the railroad a number of feeble seep springs occur along the base of a low bluff between which and the lake the ground is almost flat. Water occurs on the surface in many places, rendering the land unfit for use. Before irrigation was so extensively practiced it is reported that this lowland belt was fertile farming land, but in late years, due to the rise of the ground-water level, the land has materially decreased in value. Considerable areas of available land, however, are yet to be found in this area, and flowing wells are used to irrigate several hundred acres. Conditions can be much improved by drainage. The map and list of wells show the general conditions. The deep wells in this belt average slightly over 100 feet and generally are 2 inches in diameter. North of Provo River the yield is inconsiderable, averaging, possibly, less than 15 gallons a minute per well; but in the vicinity of Geneva, a resort on the lake below Pleasant Grove, the effect of Battle Creek drainage is experienced, and some of the strongest wells of the entire area covered by this report occur. Harry Gammon's wells, in sec. 7, T. 6 S., R. 2 E., are among the best. One of these is 3 inches in diameter, 110 feet deep, and yields a flow of about 266 gallons a minute, the water rising in a pipe to approximately 28 feet above the surface. The section in this vicinity is shown on Pl. V, the water occurring in gravel in the bottom of the well.

PROVO AND VICINITY.

Provo derives its water supply from Provo River. A number of canals tap the river (as shown on the map, Pl. VIII), and distribute a good supply to the town; and water for household purposes is delivered through city mains from a direct source in the river near the mouth of the canyon. The quality is unsatisfactory, however, and a new system is being installed whereby a better supply is obtained from a number of springs that issue from unconsolidated débris along the base of the canyon for several miles above its mouth.

Well records show fairly uniform stratigraphic conditions about Provo. Gravel usually underlies the surface to a depth of from 10 to 20 feet, and is succeeded by 20 to 30 feet of sand, below which is a considerable thickness of clay, averaging possibly 100 feet, the upper 20 or 30 feet of which is yellowish and the lower part blue. Underlying the clay a bed of gravel occurs, which is said to be underlain by clay, though about Provo it has seldom been penetrated. With minor variations this section appears to hold good over a large part of the territory adjacent to the east shore of Utah Lake. Northwest from Provo the surface gravel disappears, but clay, light above and dark below and underlain by sand and gravel, is reported in the vicinity of Geneva, American Fork, and Lehi. South of Provo, in the vicinity of Springville, similar conditions prevail. (Pl. V.)

[a] These facts were obtained from Mr. Caleb Tanner, to whom the writer is indebted for many courtesies.

The beds about Provo appear to dip toward the lake at a low angle, approximately corresponding to the slope of the surface, this being indicated by the fact that the depth at which the water-bearing gravel is found over large areas is approximately constant. In the vicinity of Provo some direct data were obtained on this point. Wells have been driven along Center street from Academy street in Provo westward to the shore of the lake. The depths at which the top of the gravel was struck in some of these wells was obtained from the driver, J. Westfall, and a line of levels was run along the surface by the United States Reclamation Service, from which it appears that the lakeward inclination of the gravel is approximately 9 feet per mile, the rate decreasing as the lake is approached. Similar conditions probably exist throughout the area studied, the slope being greatest near the mountains, while beneath the broad lowlands the strata lie more nearly horizontal.

Ground water in the vicinity of Provo can generally be obtained in the upper gravel within 10 feet of the surface. In the vicinity of the lake the gravel disappears and clay generally occupies the surface. Here, as is so general throughout the entire area, swampy conditions prevail, owing to the lowness of the region, the recession of the lake, and the rise of ground water due to irrigation.

Flowing wells exist in great number in this well-populated region, and in general an abundance of good water is obtained within 200 feet of the surface. The main water-bearing horizon is the bed of gravel that underlies the blue clay. Water is generally reached in this gravel at 150 to 200 feet from the surface, but conditions are not absolutely uniform at all places, and where the prevailing section is varied by local streaks of clay, sand, and gravel corresponding differences exist. Feeble flows are sometimes found at 100 feet, and a few wells obtain water from a depth of 360 feet, but this depth is unusual in the vicinity of Provo. The wells about Provo are generally 2 inches in diameter, and their flow may possibly average 50 gallons a minute. Among the best wells in this vicinity are those at the stations of the San Pedro, Los Angeles and Salt Lake Railroad and the Rio Grande Western Railway. These are 3 inches in diameter and 190 and 176 feet deep, respectively. In November, 1904, the Rio Grande Western well was found to flow approximately 120 gallons a minute at 2 feet above the surface under a pressure of 15½ pounds per square inch.

SPRINGVILLE AND VICINITY.

Between Provo and Springville the lowland contiguous to Utah Lake extends to the Rio Grande Railroad, above which the surface rises at a steep grade to the base of the mountains. The lowland for the most part is marshy, and the line that separates flowing and nonflowing wells lies only a short distance east of the railroad. A low scarp, which apparently marks a Pleistocene fault, can be traced immediately west of the county road for a mile or more beyond the Utah County Infirmary toward Springville. Springs occur at the base of the scarp, and the large springs at the head of Spring Creek may be associated with faulting. A number of small lakes mark the presence of these springs, and Spring Creek, whose main supply is thus derived, flows about 1,600 second-feet.

The deepest well in this area is that of the infirmary, situated near the road about midway between Provo and Springville. The well is 3 inches in diameter and 270 feet deep, and water is reported to rise in a pipe to a point 3 feet above the surface, flowing about 30 gallons a minute. In this vicinity a feeble first flow is reported at depths of 65 to 80 feet.

Springville is situated on the plain about 3 miles below the mouth of Hobble Creek Canyon, the channel of the creek passing through the town. During the irrigation season practically all of Hobble Creek water is diverted by canals that head near the base of the mountains.

Ground water in Springville is obtained from wells that usually range in depth from 20 to 30 feet, the water occurring in the top gravel. The general level of ground water in the town is reported not to have changed since the early days, and only an annual difference of a few feet is noticed between winter and summer conditions.[a]

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[a] Stevenson, J. B., well driver.

Records of wells in the vicinity of Springville show rather uniform conditions. The town generally is underlain by gravel 5 to 40 feet thick, below which blue clay occurs to a depth of about 130 feet, underlain by sand and gravel down to 180 feet; then about 50 feet of light-colored clay is encountered, followed by sand and gravel at a depth of about 230 feet. In the area nearer the lake the top gravel generally is wanting, but otherwise similar sections are reported in that locality.

Flowing wells are obtained from the two lower gravel horizons at depths of approximately 130 and 230 feet. The common occurrence of water at these two horizons implies unusual uniformity of underground conditions, and suggests a low lakeward dip, approximately corresponding to the surface inclination. The wells are commonly 2 inches in diameter, though a few are 3 inches, and they yield on an average possibly 20 to 50 gallons a minute. One of the best in Springville is a 3-inch well belonging to A. Cox. It is 230 feet deep, flows about 120 gallons a minute, and its water is reported to rise in a pipe to a point 18 feet above the surface. The Rio Grande Railway Company has two wells in Springville, which are 216 and 304 feet deep. In the deeper the first flow was struck at 126 feet, a second at 216, a third at 260, and a fourth at 292. The shallower well is 3 inches in diameter, and is reported to flow about 200 gallons a minute at the surface, which is reduced to about 12 gallons a minute at the top of a tank about 30 feet above the surface.

Mapleton Bench is the local name for the Provo Delta, lying between Spanish Fork and Hobble Creek. The delta is here prominently developed, and constitutes valuable farming land. Flowing wells are not obtained on Mapleton Bench because of its elevation, but there are a number of dug wells. It is reported that in the early days the wells on the bench were 60 feet or more in depth, but since irrigation has been practiced the ground-water level has been considerably raised, and now the wells average possibly only 30 feet in depth. There is a marked difference in the depth to ground water in winter and summer, the range in some instances amounting to over 10 feet. Along the outer margin of the bench there is a line of springs, many of which did not exist before the ditches were dug. Big Hollow Creek, a stream that flows from the bench about 2 miles south of Springville, is a conspicuous example. In the early days scarcely any water is said to have flowed in its channel, whereas it now irrigates over 100 acres.

Considerable amounts of water are obtained by a few tunnels that have been dug along the eastern edge of Mapleton Bench. The entrances to the tunnels are commonly at the sites of springs. Some begin and end in unconsolidated materials, while others penetrate bed rock. The longest noted is in sec. 24, T. 8 S., R. 3 E. Its length is 275 feet. Water enough to irrigate about 100 acres comes through crevices in bed rock.

SPANISH FORK, PAYSON, AND VICINITY.

The town of Spanish Fork is situated on the general lowland at the base of Mapleton Bench and immediately north of Spanish Fork, about 5 miles below the mouth of its canyon. From the few well records available it appears that sand and gravel commonly underlie the surface to a depth of about 30 feet and are succeeded by 150 feet of clay, below which water-bearing gravel is usually encountered at a depth of 180 feet. The log of the well recently completed at the San Pedro station, about a mile west of the town, shows a greater thickness of clay, amounting to 205 feet, beneath which sand and clay were found to 390 feet, where water-bearing gravel occurs.

Spanish Fork is rather poorly supplied with underground water. Dug wells commonly reach water at depths ranging from 10 to 25 feet, but its quality is not good. Flowing wells were formerly obtained, but in recent years the flows generally have ceased and pumping has to be resorted to. A city waterworks system was installed in 1904, the supply being derived from Evans Spring, near the mouth of Spanish Fork Canyon, about 5 miles above the town, and an excellent supply is now available. The line separating flowing and nonflowing wells now lies in the extreme northwest corner of the town. The first flow occurs at a depth of about 180 feet and a second flow between 350 and 400 feet. The creamery well, 2 inches in diameter and 220 feet deep, is typical. Water was struck at 180 feet

which in 1900 flowed 9 gallons a minute, while in 1904 it stood about 4 feet below the surface with little or no variation. In 1904 the San Pedro, Los Angeles and Salt Lake Railroad Company put down a well 415 feet deep at its Spanish Fork station and obtained a flow of 36 gallons a minute through a 2-inch pipe from gravel in the bottom of the well.

Between Spanish Fork and the Goshen divide there are a number of settlements that are adjacent to the line separating flowing and nonflowing wells.

Salem is situated at the lower end of the Provo Bench, about midway between Spanish Fork and Payson. In the northwestern part of the town the water table lies close to the surface and throughout the greater part of the settlement water can be obtained within 10 feet of the surface. There are many springs, the most important of which supply Salem Pond, which covers about 13 acres and averages possibly 12 feet in depth. The line separating flowing and nonflowing wells passes about midway through Salem. The flowing wells are generally feeble and the quality of the water is poor. A first flow is commonly obtained at about 160 feet and a second at about 250 feet.

Payson is situated on and near the delta formed by Peteneet Creek at the Provo stage of Lake Bonneville, part of the town being built on the delta and part on the subjacent plain. Flowing wells are not obtainable because of the elevation, and the underground water supply is furnished by dug wells. These vary considerably in depth because of the irregular distribution of the delta deposits. Their depth ranges from 15 to 115 feet and probably averages between 30 and 40 feet. As an instance of local variation it may be mentioned that in one well ground water is obtained at 18 feet while on the opposite side of the street a well was dug 90 feet without encountering water. The level of ground water is reported to fluctuate but little. A number of families in Payson are supplied by pipe lines, the water being derived from tunnels driven into the base of the bench.

The town of Spring Lake is situated near the base of the mountains. The line separating flowing and nonflowing wells passes along the foot of the Provo Bench and lies about half a mile west of the town. In this locality ground water is found commonly within 10 feet of the surface and there are a number of shallow wells, but the chief supply comes from springs. Spring Lake covers an area of about 12 acres and discharges a stream of about 2 second-feet. It is made by damming a small creek that is fed by springs. Springs occur in the vicinity of the base of the mountains between Spanish Fork and Spring Lake. Most of them appear to be seep springs, but some that lie near faults that adjoin the base of the mountains may be of deeper seated origin. Many of the springs flow 20 to 50 gallons a minute.

Santaquin is built on a delta of Santaquin Creek, near the base of the mountains, far above the general level at which flowing wells are obtained. The town is chiefly supplied with water for both household and irrigation uses by Santaquin Creek, and only a few wells have been dug. About a dozen wells strike water in gravel at depths of between 15 and 25 feet on a low bench in the southeastern part of the town. Tunnels are also dug into this bench, from which two pipe lines supply a number of families with water. Below the bench in Santaquin there are very few wells; two had to be dug about 80 feet before water was obtained.

Below the line separating flowing and nonflowing wells between Hobble and Santaquin creeks the valley plain slopes gently to Utah Lake. Throughout this area ground water lies within 10 feet of the surface, and adjacent to the lake and in certain isolated localities swampy conditions occur. This area is mostly underlain by clay, which is reported to predominate in all of the wells. Little or no gravel is encountered in well driving and the layers of clay alternate with layers of sand. Few satisfactory well records from this region have been obtained, and no correlation of the underground deposits has been possible. Different conditions seem to exist in neighboring wells, indicating a lenticular arrangement of the deposits.

The towns of Palmyra, Lake Shore, and Benjamin are situated below the line of flowing wells. Many farms are scattered over this area, but in a few localities—north of Spanish Fork, for instance—alkali is so prevalent as to discourage settlement. Much of the water used in irrigating this tract is derived from canals supplied by Spanish Fork, but flowing wells also are used to a considerable extent.

Flowing wells have been obtained throughout this area at depths of 50 to 500 feet, as shown by the list. Flows are usually found in every considerable bed of sand encountered in drilling, and six or more water-bearing beds are sometimes struck in a 400-foot well. Shallow wells are not the rule in this region, for, though many are 150 to 200 feet deep, the majority are nearer 400 feet deep. Because of the general absence of gravel and of persistent beds of sand there are few especially good wells. The flows obtained are generally under 50 gallons a minute and frequently are less than 10. The pressure is low, seldom being sufficient to cause the water to rise more than a few feet above the surface.

At the southern end of the lake, north of West Mountain, just above low-water level there is a warm spring that was estimated to flow 200 gallons a minute. Its temperature is 88°.

GOSHEN VALLEY.

Goshen Valley can be divided into a highland and a lowland portion, a convenient line of division for present purposes being that which separates areas where ground water lies above 10 feet from the surface, from those in which it lies below that depth. The highland lies contiguous to the mountains and merges into the lowland which adjoins the lower course of Currant Creek and the southern extremity of Utah Lake. The lowland is chiefly underlain by clay and the soils contain abundant alkali.[a] Throughout the entire area ground water lies close to the surface and marshy conditions exist, especially toward the lake.

The area of flowing wells in Goshen Valley embraces about 15 square miles and extends from Utah Lake to within about a mile of Goshen. Within it flowing wells are obtained at depths ranging from 50 to 400 feet. From the few available records it appears that varying stratigraphic conditions exist in this area, the prevailing clay being irregularly interbedded with sand, usually in thin streaks, with very little gravel. The flows obtained are small, averaging possibly about 5 gallons a minute, and the pressure is sufficient to cause the water to rise only a few feet above the surface.

Goshen itself is furnished with surface water from ditches supplied by Currant Creek and by springs located at the base of the hills about 2 miles east of the town. The underground supply is derived from wells that usually range from 25 to 75 feet in depth. The wells are put down through clay to sand in which water is found under pressure sufficient to cause it to rise almost to the surface, the usual depth to water being 3 to 20 feet. A number of unsuccessful attempts to get flowing wells have been made, the deepest being the railroad well put down near the station. It is 334 feet deep, and water is reported to have risen in it to within a few feet of the surface.

The highland area is underlain chiefly by coarse detritus derived from the adjacent mountains and distributed either as shore deposits in Lake Bonneville or as alluvial accumulations. This higher portion of Goshen Valley is poorly supplied with water, the chief sources being Kimball Creek, a small stream which seldom flows below its mountain course, and Currant Creek, which flows perennially and supplies the lower valley. The discharge of Currant Creek, however, is insufficient for the needs of the upland. A reservoir has been built by damming Currant Creek at the entrance to its canyon course through Long Ridge, and a canal constructed which skirts the upper part of Goshen Valley, but the enterprise has been a failure.

A few springs occur along the eastern base of the Tintic Mountains and some successful attempts have been made there to develop underground water by tunneling. In the upper valley of Kimball Creek there are a number of springs which flow about 100 gallons a minute, and smaller ones occur in several gulches. About 2 miles east of Goshen there is a group of springs at the base of Long Ridge, where water issues through débris and accumulates in several small ponds, the temperature of which is reported to stay at about 70° F. throughout the year. These springs constitute the source of Warm Creek, and their combined flow in November, 1904, was estimated at about 5 second-feet. Water has been developed

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[a] Sanchez, A. M., Soil survey of the Provo area, Utah: Bull. Bureau of Soils, U. S. Dept. Agric., 1904.

by tunneling at several localities along the eastern slope of the Tintic Mountains. In the valley of Kimball Creek, in sec. 11, T. 11 S., R. 2 W., there is a tunnel 200 feet long in volcanic rock, which furnishes about 20 gallons a minute, and water sufficient for milling purposes has been developed by drifting into the alluvium and bed rock at the head of Homansville Canyon.[a]

Away from the bordering mountains in the highland portion of Goshen Valley, very little underground water has been obtained, and considering the slight run-off and the small tributary drainage area, not much can be expected. The most favorable locations for sinking wells are along the courses of drainage ways. The most successful are along the course of Kimball Creek, but even there water commonly is not obtained at depths less than 150 feet. A number of dry wells have been sunk in the upland area.

WEST OF UTAH LAKE.

The narrow strip of lowland between the western shore of Utah Lake and the Lake Mountains is very scantily provided with water. The low, narrow mountains catch relatively little precipitation; there are no perennial streams, and the arroyos carry water only for a few days during the year. From the foot of the Bonneville and Provo terraces that extend along the base of the mountains the surface slopes gradually lakeward and is underlain chiefly by coarse-textured deposits.

Along the shore of the lake a number of seep springs occur near water level. They are most abundant from Lehi southward, and there are also a few 2 or 3 miles beyond Pelican Point, where their presence is marked by low, marshy areas, one of which is utilized in the cultivation of a few acres of alfalfa. Near Pelican Point there is a feebly flowing well 90 feet deep, in which water was obtained at a depth of 60 feet; and in a near-by well a feeble flow is also obtained, which is said to come from a depth of 154 feet.

Few if any other attempts have been made to recover underground water in this region. Judging from the wells at Pelican Point one might expect to obtain similar results along the western shore of the lake, but if flows were obtained the water would be at so low an elevation as to make it of little use without pumping. Away from the shore flows can hardly be expected. It may be, however, that limited amounts of water can be found to rise in wells to within pumping distance. Prospecting for shallow wells might be attempted in the arroyos, but because of the limited watershed and precipitation the prospect is not good for obtaining enough underground water for extensive irrigation. Pumping directly from the lake presents attractive possibilities.

WELL DATA.

The writer is indebted for the subjoined list of wells to Messrs. F. D. Pyle and T. F. McDonald. Mr. Pyle worked in Utah Lake Valley and west of Jordan River. Mr. McDonald, whose assistance was obtained through the courtesy of Mr. George W. Snow, engineer of Salt Lake City, collected data east of Jordan River. The yield of flowing wells was commonly measured by means of tables which are here inserted, together with accompanying explanation, because the method aroused popular interest and because the edition of the bulletin in which the tables were published has been exhausted.

METHOD OF MEASUREMENT.[b]

Tables for determining the discharge of water from completely filled vertical and horizontal pipes were prepared a number of years ago by Prof. J. E. Todd, State geologist of South Dakota, who issued a private bulletin describing simple methods of determining quickly, with fair accuracy and with little trouble, the yield of artesian wells. In the following notes the tables and explanations relating to vertical and horizontal pipes are taken from this bulletin. The explanations have been appended by the present writer.

[a] Smith, G. O., and Tower, G. W., Description of the Tintic district: U. S. Geologic Atlas, special folio 65, U. S. Geol. Survey, 1900.

[b] Slichter, C. S.: Water-Sup. and Irr. Paper No. 110, U. S. Geol. Survey, 1905, pp. 37–42.

In determining the flow of water discharged through a pipe of uniform diameter all that is necessary is a foot rule, still air, and care in taking measurements. Two methods are proposed—one for pipes discharging vertically, which is particularly applicable before the well is permanently finished, and one for horizontal discharge, which is the most usual way of finishing a well.

The table [on page 58] is adapted to wells of moderate size, as well as to large wells. In case the well is of other diameter than given in the table its discharge can without much difficulty be obtained from the table by remembering that, other things being equal, the discharge varies as the square of the diameter of the pipe. If, for example, the pipe is one-half inch in diameter its discharge will be one-fourth of that of a pipe 1 inch in diameter for a stream of the same height. In a similar manner the discharge of a pipe 8 inches in diameter can be obtained by multiplying the discharge of the 4-inch pipe by 4.

In the first method the inside diameter of the pipe should first be measured, then the distance from the end of the pipe to the highest point of the dome of the water above in a strictly vertical direction—*a* to *b* in the diagram [fig. 5]. Find these distances in table [p. 58, A] and the corresponding figure will give the number of gallons discharged each minute. Wind would not interfere in this case so long as the measurements are taken vertically.

The method for determining the discharge of horizontal pipes requires a little more care. First measure the diameter of the pipe, as before, then the vertical distance from the center of the opening of the pipe, or some convenient point corresponding to it on the side of the pipe, vertically downward 6 inches, *a* to *b* of the diagram, then from this point strictly horizontally to the center of the stream, *b* to *e*.

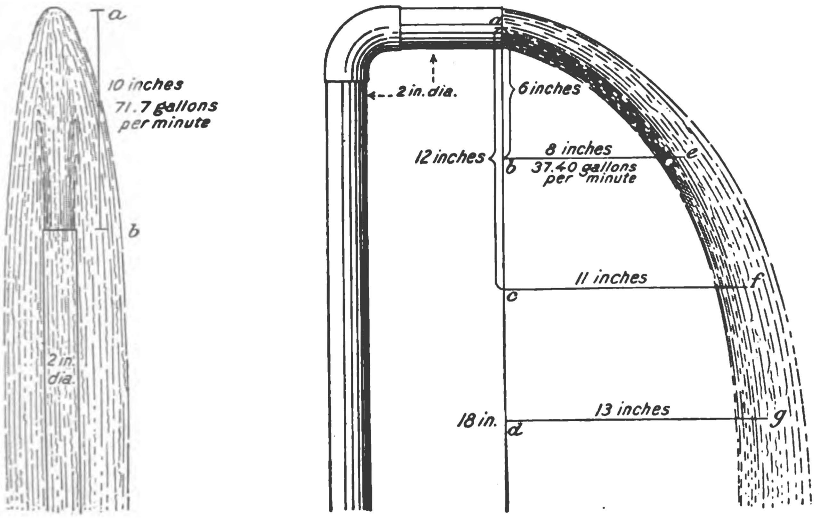

FIG. 5.—Diagram illustrating flow from vertical and horizontal pipes.

With these data the flow in gallons per minute can be obtained from table [p. 58, B]. It will readily be seen that a slight error may make much difference in the discharge. Care must be taken to measure horizontally and also to the center of the stream. Because of this difficulty it is desirable to check the first determination by a second. For this purpose columns are given in the tables for corresponding measurements 12 inches below the center of the pipe. Of course the discharge from the same pipe should be the same in the two measurements of the same stream. Wind blowing either with or against the water may vitiate results to an indefinite amount. Therefore measurements should be taken while the air is still.

Whenever fractions occur in the height or horizontal distance of the stream, the number of gallons can be obtained by apportioning the difference between the readings in the table for the nearest whole numbers, according to the size of the fraction. For example, if the distance from the top of the pipe to the top of the stream in the first case is 9⅓ inches, one-third of the difference between the reading in the table for 9 and 10 inches must be added to the former to give the correct result.

In case one measures the flow of a well by both methods he may think that the results should agree, but such is not the case. In the vertical discharge, there being less friction, the flow will be larger; so, also, in the second method differences will be found according to the length of the horizontal pipe used.

As pipes are occasionally at an angle, it is well to know that the second method can be applied to them if the first measurement is taken strictly vertically from the center of the opening and the second measurement from that point parallel with the axis of the pipe to the center of the stream, as before. The measurements can then be read from the table.

Table for determining yield of artesian wells.

[Gallons per minute.]

A.—Flow from vertical pipes.

Height of jet.	Diameter of pipe in inches. 1.	1¼.	1½.	2.	3.
Inches.					
½	3.96	6.2	8.91	15.8	35.6
1	5.60	8.7	12.6	22.4	51.4
2	7.99	12.5	18.0	32.0	71.9
3	9.81	15.3	22.1	39.2	88.3
4	11.33	17.7	25.5	45.3	102.0
5	12.68	19.8	28.5	50.7	113.8
6	13.88	21.7	31.2	55.5	124.9
7	14.96	23.6	33.7	59.8	134.9
8	16.00	25.1	36.0	64.0	144.1
9	17.01	26.6	38.3	68.0	153.1
10	17.93	28.1	40.3	71.6	161.3
11	18.80	29.5	42.3	75.2	169.3
12	19.65	30.7	44.2	78.6	176.9
13	20.46	31.8	45.9	81.8	184.1
14	21.22	33.0	47.6	84.9	190.9
15	21.95	34.2	49.3	87.8	197.5
16	22.67	35.2	50.9	90.7	203.9
17	23.37	36.3	52.5	93.5	210.3
18	24.06	37.5	54.1	96.2	216.5
19	24.72	38.6	55.6	98.9	222.5
20	25.37	39.6	57.0	101.6	228.5
21	26.02	40.6	58.4	104.2	234.3
22	26.66	41.6	59.9	106.7	240.0
23	27.28	42.6	61.4	109.2	245.6
24	27.90	43.5	62.8	111.6	251.1
25	28.49	44.4	64.1	114.0	256.4
26	29.05	45.3	65.3	116.2	261.4
27	29.59	46.1	66.4	118.2	266.1
28	30.08	46.9	67.5	120.3	270.4
29	30.55	47.5	68.5	121.9	274.1
30	30.94	48.2	69.4	123.4	277.6
36	34.1	53.2	76.7	136.3	306.6
48	39.1	61.0	88.0	156.5	352.1
60	43.8	68.4	98.6	175.2	394.3
72	48.2	75.2	108.0	192.9	434.0
84	51.9	81.0	116.8	207.6	467.0
96	55.6	86.7	125.0	222.2	500.0
108	58.9	92.0	132.6	235.9	530.8
120	62.2	98.0	139.9	248.7	559.5
132	65.1	102.6	146.5	260.4	585.9
144	68.0	106.4	153.1	272.2	612.5

B.—Flow from horizontal pipes.

Horizontal length of jet.	1-inch pipe. 6-inch level.	1-inch pipe. 12-inch level.	2-inch pipe. 6-inch level.	2-inch pipe. 12-inch level.
Inches.				
6	7.01	4.95	27.71	19.63
7	8.18	5.77	32.33	22.90
8	9.35	6.60	36.94	26.18
9	10.51	7.42	41.56	29.45
10	11.68	8.25	46.18	32.72
11	12.85	9.08	50.80	35.99
12	14.02	9.91	55.42	39.26
13	15.19	10.73	60.03	42.54
14	16.36	11.56	64.65	45.81
15	17.53	12.38	69.27	49.08
16	18.70	13.21	73.89	52.35
17	19.87	14.04	78.51	55.62
18	21.04	14.86	83.12	58.90
19	22.21	15.69	87.74	62.17
20	23.37	16.51	92.36	65.44
21	24.54	17.34	96.98	68.71
22	25.71	18.17	101.60	71.98
23	26.88	18.99	106.21	75.26
24	28.04	19.82	110.83	78.53
25	29.11	20.64	115.45	81.80
26	30.38	21.47	120.07	85.07
27	31.55	22.29	124.69	88.34
28	32.72	23.12	129.30	91.62
29	33.89	23.95	133.92	94.89
30	35.06	24.77	138.54	98.16
31	36.23	25.59	143.16	101.43
32	37.40	26.42	147.78	104.70
33	38.57	27.25	152.39	107.98
34	39.64	28.08	157.01	111.25
35	40.45	28.64	161.63	114.52
36	41.60	29.46	166.25	117.79
Continue by adding for each inch —	1.15	0.82	4.62	3.27

NOTE.—To convert results into cubic feet, divide the number of gallons by 7.5, or, more accurately, by 7.48.

The flow in pipes of diameters not given in the table can easily be obtained in the following manner:

For ½-inch pipe, multiply discharge of 1-inch pipe by 0.25
For ¾-inch pipe, multiply discharge of 1-inch pipe by .... .56
For 1¼-inch pipe, multiply discharge of 1-inch pipe by 1.56
For 1½-inch pipe, multiply discharge of 1-inch pipe by 2.25
For 3-inch pipe, multiply discharge of 2-inch pipe by 2.25

For 4-inch pipe, multiply discharge of 2-inch pipe by 4.00
For 4½-inch pipe, multiply discharge of 2-inch pipe by 5.06
For 5-inch pipe, multiply discharge of 2-inch pipe by 6.25
For 6-inch pipe, multiply discharge of 2-inch pipe by 9.00
For 8-inch pipe, multiply discharge of 2-inch pipe by 16.00

LIST OF TYPICAL WELLS.

Wells in Jordan River and Utah Lake valleys.

[Height of water above surface indicated by plus +; below surface indicated by minus —.]

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
B. Young	T. 1 N., R. 1 E., sec. 31		75	—	
J. L. Haywood	do		61	—	
R. R. Anderson	do		48	—	
C. R. Savage	T. 1 N., R. 1 E., sec. 32		35	—	
G. A. Hatch	T. 1 N., R. 1 W., sec. 1		18	—14	
J. Howard	do	2	312	+	½
Stockyards	T. 1 N., R. 1 W., sec. 3	2		+	5
T. German	T. 1 N., R. 1 W., sec. 4	2½		+	1½
F. S. Rudy	T. 1 N., R. 1 W., sec. 5	6	1,002	+	Many.
J. E. Peterson	T. 1 N., R. 1 W., sec. 9	2	497	+	6
J. Minegar	T. 1 N., R. 1 W., sec. 10	1½	150	+	1½
Do	do	1½	250	+	5
R. A. Bosley	T. 1 N., R. 1 W., sec. 11	1½	50	—20–50	
J. C. Hansen	T. 1 N., R. 1 W., sec. 15	2	479	+	
W. S. McDonald	T. 1 N., R. 1 W., sec. 17	2	400	+	40
Gun Club	T. 1 N., R. 1 W., sec. 21	2	450	+	30
J. Herridge	T. 1 N., R. 1 W., sec. 22	1½	160	+	3–7
G. Baldwin	do	2	330	+	3
C. A. Anderson	T. 1 N., R. 1 W., sec. 23		28	—	
P. Olene	do		26	—	
S. Bamberger	T. 1 N., R. 1 W., sec. 25	2	60–70	+	
G. Fritt	do	1½	80	+	2
J. Withers	do	1½	70	—	
I. Langton	T. 1 N., R. 1 W., sec. 26	2	400	+	3
G. Martin	do		140	+	1–2
A. J. Davis	T. 1 N., R. 1 W., sec. 27	2	154	+	1
F. W. Kettle	do	2	208	+	
A. M. Davis	T. 1 N., R. 1 W., sec. 34	2	408	+	25
Do	do	1½	250	+	1
E. King	do	2	320	+	1½
Wantland	do	2	350	+	1
J. J. Sears	T. 1 N., R. 1 W., sec. 35	1½	140	+	
Do	do	2	210	+	5
Do	do	2	350	+ 1	15
P. Cline	do	1½	135	+	2
R. Weisner	do	2	130	+	3
J. W. Evans	do	1½	68	+	2
W. Pearson	T. 1 N., R. 1 W., sec. 36	1½	93	+	15
J. W. Haddock	do	2	95	+	35
A. Elkins	do	2	123	+	30
A. J. Ridges	do	1½	100	+	25
W. Spicer	do	1½	75	+	5–20
J. Sandborg	do		75	—	
H. Price	do	1½	75	—	
Mrs. Winters	do	2	96	—	
R. Griffith	do	2	200	+	20

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
S. A. Gibbs	T. 1 N., R. 1 W., sec. 36	2-3	75-80	+	40
F. Auerbach	T. 1 N., R. 2 W., sec. 25		400		
J. Bond	T. 1 N., R. 2 W., sec. 29		401	+	4
Do	do		465	+	9
Cullen Dairy	T. 1 N, R. 2 W., sec. 35	2		+	
J. Walker	T. 1 S., R. 1 E., sec. 5	1½	80	+	20
P. J. Stone	do		16	− 6	
J. Lunn	do		73	−	
W. J. Kelson	do		45	−	
S. McKay	do		29	−	
Speirs	do		40	−12	
Do	do		12	− 6	
J. E. Wesley	T. 1 S., R. 1 E., sec. 6		75	−	
J. Warburton	do	2	82	+	7
H. S. Sampson	do	2	387	+	8
W. Wheeler	do		10	−	
T. Golightly	do	1½	100	+	
S. K. Hansen	do	2	162	+	6-8
W. N. Sheets	T. 1 S., R. 1 E., sec. 7	2	100	+	30
F. Sproul	do	2	125	+	½
G. Baiber	do		170	+	12
F. Rogansky	do		150	+	1
City, about 16 wells	do	2-9	100-600	+35	(?) 600
E. O. Butterfield	do	2	178	+	2-3
J. S. Wooley and others	do		150-200	+	20-50
T. Berg	do	2	155	+	50
Do	do	2	160	+	50
W. Colton	do	2	60	+	6
L. Badger	do	2	165	+	30
J. W. Hicks	do	2	110	+	35
A. Duncan	T. 1 S., R. 1 E., sec. 8	1½	50	− 1	
T. Antisill	do	2	50	+	3
S. M. Alley	do	3	26	−	
S. H. Calder	do	2	246	+	40
S. Sudbury	do	1½	390	+	8
J. R. Miller	do	2	207	+12	50
P. Rosmason	do		41	−	
Mrs. M. Larsen	do		28	− 5- 6	
W. Pickens	do		42	− 7	
A. Ames	T. 1 S., R. 1 E., sec. 9		100	−	
A. S. Martin	T. 1 S., R. 1 E., sec. 10		130	−	
J. A. Shelter	T. 1 S., R. 1 E., sec. 15		85	−65	
L. Hunt	do		51	−30-50	
A. Hord	T. 1 S., R. 1 E., sec. 16		54	−	
A. Martin	do		56	−46	
H. E. Thorp	do		18	−	
J. S. Southern	T. 1 S., R. 1 E., sec. 17		32	−	
A. Buggs	do		22	− 4-16	
J. E. Nailor	do		20	− 5-14	
T. Y. Taylor	do	2	100	−	
(a)	do	2	200	+	6
W. H. Miller	do	2	335	+	50
W. H. Burnett	do		15	− 3-11	
M. C. Sandford	do		33	− 3	

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
J. A. James	T. 1 S., R. 1 E., sec. 17		33	−28	
(a)	do		10	−	
G. Hemsley	do		14	−	
J. Hemsley	do		48	−43	
J. J. Hurtt	T. 1 S., R. 1 E., sec. 18	2	325		4-5
T. Furgeson	do	2	300	+	30-40
W. N. Sheets	do	2	100	+	30
M. Gray	do	2	164	+	10
F. H. Woodbury	do		160	+	18
M. P. Holmes	do		20	−	
E. H. Stout	do	2	72-82	+	30-40
J. H. Cochran	do	2	500	+	5
F. Prittish	do	2	600	+	12-14
Salt Lake Co	do	2	636	+	(?) 150
E. Jepson	do	2	150	+	10
F. Wittich	do	2	40	+	18
L. A. Kelsh	do	2	325-350	+	30-40
D. Evans	do		501	+	80
Erickson	do	3	382	+	(?) 100
I. Riches	do		17	−	
M. Chophussen	do	2	250-300	+	1-13
E. S. Pierce	do	2	322	+	55
(a)	do		560	+	20-30
W. H. Wolstezhoh	do	3	40	−	
C. B. Stock	do	2	298	+	10-12
J. I. Freeman	do	2	100	+	5-6
H. Best	do	1½	50	+	8
A. Best	do		160-170	−	
J. A. Bush	T. 1 S., R. 1 E., sec. 19	3	323		
J. H. Tipton	do	2	296	+	50-60
L. W. Burton	do	2	285	+	60
Do	do	2	150	+	25
Do	do	2	437	+	10-20
Do	do		100		
J. Riley	do	2	94	+	17-20
G. Hall	do	2	60	+	1
J. C. Hogan	do	2	176	+	18
J. O. Young	do	2	180	+	20-25
R. B. Young	do		90	+	20-25
M. W. Taylor	do	2	181	+	(?) 100
L. H. Kimball	do	1¾	84	+	10
Do	do	2	212	+	1
W. C. Winder	do	2	75	+	
Do	do	2	240	+	
A. Walker	do			+	30
(a)	do		150		40
E. P. Parrot	do	2	150-160		46
H. Behling	T. 1 S., R. 1 E., sec. 20		23	−20	
H. Eldridge	do		26		
T. R. Cutler	do	3	65		
S. Love	do		40	+	5-6
M. C. Morris	do		162	+	½
N. J. Hansen	do	2	156	+	28
A. Hoskinson	do		21	−14-15	

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
C. Hansen	T. 1 S., R. 1 E., sec. 20		22	− 18	
P. R. Ryon	do		158	+	80
G. Cusiman	do		18	− 15	
W. C. Smoot	do		22	− 19	
J. Neff	T. 1 S., R. 1 E., sec. 26		23	−	
C. Banford	do		100	−	
J. Fisher	T. 1 S., R. 1 E., sec. 27		33	− 20	
J. Young	do		184	−104	
F. Ereickson	T. 1 S., R. 1 E., sec. 28		27	− 25	
J. Childs	T. 1 S., R. 1 E., sec. 29		55	−	
W. M. Tillman	do		68	−	
F. Degenhart	do	2	68	− 37	
J. P. Cahoon	do		26	−	
W. S. Timmons	do	2	194	+	9
J. T. Guest	do	2	187	−	
R. Pike	do		40	− 34	
J. Madsen	do		260	− 16	
J. S. Gustavensen	do	2	190	+	2
H. Hizzard	do		200	+	2
Mrs. C. Green	do		184	−	
Do	do		215	+	11
S. F. Evans	do	2	208	−	
O. Reece	do		209	+	30
Do	do		245	+	30
Do	do		245	+	13
L. Stutts	do	2	141-143	+	40
S. Hicks	do	2	100	+	30
E. E. Keithley	do	3	120	+	(?) 100
H. Burnett	do		202	+	27
Do	do		24	−	
W. J. Miller	do	2	200	+	20
G. Fairbourne	do	2	128	+	20
J. Tremayave	T. 1 S., R. 1 E., sec. 30	2	251	+	20
G. Taylor	do		104	+	
W. Chantron	do	2	235	+	30
J. J. Spencer	do	2	240	+	17
M. M. Listen	do	2	110	+	5
J. Cobert	do		216	+	24
School	do	2	218	+	12
G. Calder	do	2	130	+	45
R. Norman	do	1½	100	+ 6	
Mrs. A. S. Berg	do	2		+	28
A. Johansen	do	2	175	+	8
(a)	do	2		+	30
Murray Live Stock Co.	do	2		+	40-60
M. Knudsen	do		300	+	20
L. White	do		185-230	+	60
E. J. Williams	do	2	82-83	+	25
Do	do	2	50	+	1
C. Halford	do	1½	160	+	10
A. M. Rymarson	T. 1 S., R. 1 E., sec. 31	2	202	+	35
Do	do	2	72	+	6
L. Parks	do	2	237		
J. Hulse	do	2	160	+	20

[a] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
J. Hulse	T. 1 S., R. 1 E., sec. 31	2	130	+	20
Do	do	2	255	+	30
J. Pearson	do		83	+	
C. Bell	do	2	209	+	40
Do	do		211	+	20
J. Bert	do	2	203	+	12
C. Cramer	do		150	+	(?) 110
Do	do		90	+	
N. White	do		130	+	15
J. Anderson	do		80	+	½
S. Haslam	do	2	244	+	8
E. Huish	T. 1 S., R. 1 E., sec. 32	2	210	+	28
Do	do		70	+	35
S. W. Moyle	do		196	+	6
J. Cornwell	do		235	+	20
Do	do		160	+	
Do	do		160	+	1-12
Do	do		165	+	
S. A. Cornwell	do	2	193	+	1
Do	do	2	55	+	
A. Young	do		33	− 24	
E. Bailey	do		25	− 22	
L. E. Sowers	do		54-56	−	
J. W. Murphy	do		70-150	−	
C. A. North	T. 1 S., R. 1 E., sec. 33		25	−	
W. H. Thuers	do	3	520	−419	
P. C. Brizen	do	3	350	+	25
Mrs. M. Cold	T. 1 S., R. 1 W., sec. 1	1½	317	+	1
J. R. Morgan	do	2	300	+	20
Mrs. E. R. Wadsen	do	1½	202	+	2
(a)	T. 1 S., R. 1 W., sec. 2	2	120	+	
J. Harrison	do	3	1,100	+	30
F. J. Guth	do	2	114	+	1½
Mrs. C. Bickson	do	2	318	+	6
J. H. Haward	do	2	335	+	4
J. Taylow	do	1	95	+	2½
Rio Grande Rwy	do	4	1,072	+ 30	80
H. L. Eyler	T. 1 S., R. 1 W., sec. 3	2½	381	+	16
Mortensen	T. 1 S., R 1 W., sec. 4	2	280	+	3
R. Boss	T. 1 S., R. 1 W., sec. 5	2	360	+ 4½	7
E. B Swan	do	2	385	+	6
J. Rodgers	T. 1 S., R. 1 W., sec. 7	1½	154	−	
Do	do	2	405	+	10
Do	do	1½	154	+	
F. Schonfeld	T. 1 S., R 1 W., sec. 8	2	325	+ 1	1
Brighton School	T. 1 S., R. 1 W., sec. 9	2	320	+	5-6
H. J. Walk	do	1½	98	+ 1	1
H. E. Evans	T. 1 S., R. 1 W., sec. 10	3	624	+	30-40
W. Baden	T. 1 S., R. 1 W., sec. 11	2	377	+	9
W. J. Kinsman	do	2	130	+	20-30
Cannon	do		165	+	6-7
Sudbury	do	2		+	25
A. Bailey	do	2	367-387	+	5-6
J. Cleveland	do	2	456	+	60-70

[a] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
E. Kidd	T. 1 S., R. 1 W., sec. 12	2	475	+	25
A. H. White	do		300	+	5–15
J. Anderson	T. 1 S., R. 1 W., sec. 13		400		60
J. H. Shaffer	do		18		
Lambert Paper Co	do	2	177		10
R. Cutler	do	2	315	+	45
J. Gabbot	do	2	380	+	10–15
(a)	do	2	275	+	16
J. S. McCallan	T. 1 S., R. 1 W., sec. 14		355	+	25
J. G. Gumman	T. 1 S., R. 1 W., sec. 16	2	330	+	25
Schoolhouse	T. 1 S., R. 1 W., sec. 17	2	400	+	12
S. C. Sudbury	T. 1 S., R. 1 W., sec. 18	2	412	+12	25
L. S. Hansen	T. 1 S., R. 1 W., sec. 21	1½		+	15
N. Hansen	T. 1 S., R. 1 W., sec. 24		145	−	
S. Sorensen	do	2	385	−	
Gilchrist	T. 1 S., R. 1 W., sec. 25	1½	130	−	
Rockhill	do	2	120	+	5
P. Austin	do	2	145	−	
G. H. Walton	do	2	350	+30	
B. Harmon	T. 1 S., R. 1 W., sec. 26	2	350	+30	
(a)	T. 1 S., R. 1 W., sec. 28	1½	290	−	
Murray	do			+	6
C. J. Lambert	T. 1 S., R. 1 W., sec. 29		182	+	1
L. Burden	do		70	−	
N. P. Peterson	T. 1 S., R. 1 W., sec. 31		50	−30	
J. C. Poulton	do		60	−51	
(a)	T. 1 S., R. 1 W., sec. 32	1½	290	−	
T. R. Jones	T. 1 S., R. 1 W., sec. 35	2	345	−	
Do	do	1½	75	−	
(a)	T. 1 S., R. 1 W., sec. 36	1½	140	+	2
J. P. Anderson	T. 1 S., R. 2 W., sec. 1		160	−	
(a)	do	2	260	+	5
(a)	T. 1 S., R. 2 W., sec. 14	2	150	+	3
Wolstenholm	T. 1 S., R. 2 W., sec. 21	1½	30	+	10
Spencer	do		68	+	2
Oslen	do	3	150	+	
Butterworth	do	1½	175	+	15
T. West	T. 1 S., R. 2 W., sec. 22	2	40	+	6
N. T. West	do	1½	40	+ 3	12
J. Michaels	T. 1 S., R. 2 W., sec. 23	1½	90	+ 6	25
J. Hayhoe	T. 1 S., R. 2 W., sec. 26	1½	177	+	5
Goodwin	T. 1 S., R. 2 W., sec. 27		27	−21	
A. Cockerill	T. 1 S., R. 2 W., sec. 29	1½	118	−14	
Speirs	T. 1 S., R. 2 W., sec. 33		84	−	
J. Kersey	T. 1 S., R. 2 W., sec. 34	42	166	−66	
Inland Crystal Salt Co.	T. 1 S., R. 3 W., sec. 2	4	720	+ 9	8
Salt Lake and Los Angeles Rwy. Co.	do		330	+12	20
P. J. Reid	T. 1 S., R. 3 W., sec. 24		134	+	9
J. Bertock	do	1½	73	+	3
J. Neilson	T. 2 S., R. 1 E., sec. 3	4	540	−	
G. Coleman	do		62	−	
T. Newman	do		65	−	
T. Gundesser, jr	T. 2 S., R. 1 E., sec. 4		18	−	Dry.

[a] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
T. R. Brockbank	T. 2 S., R. 1 E., sec. 4		104	+	46
Do	do		102	+	25
J. Southerland	do	2	76	+	15
Do	do	2	78	+	24
Do	do	2	99	+	4
Do	do	3	232	−	
W. Templeman	do	2	225	−	
F. Hopp	do	2	70–100	+	20–34
A. Fuller	do	2	65	+	4
Do	do		335	+	20
P. C. Brizen	do	3	122	−70	
J. Wright	T. 2 S., R. 1 E., sec. 5		200	+	1½
E. Pugh	do	2	108	+	25
S. A. Williams	do	2	180	+	3–5
Mrs. A. D. Park	do		90	+	2
O. Lemon	do		384	+	5
H. J. Bullock	T. 2 S., R. 1 E., sec. 6	2	100	+	10
T. Powell	do	2	194	+	10
H. Park	do	2	90	+	32
W. Hill, sr	do	2	255	+	28
Do	do	2	80	+	4
W. Hill, jr	do	2	255	+	40
G. E. Christensen	do	2	210	+	20
J. Godfrey	T. 2 S., R. 1 E., sec. 7	2	150	+	40
I. Hackley	do	3	115	+	1
Mrs. B. Erickson	do	2	80	+	30
J. S. Williams	do	2	315	+	15
A. E. Williams	do	2	100	+	4
L. Williams	do		190	+	10
T. Martin	do	2	189	+	38
E. Warenski	do		230	+	
C. E. Warenski	do		300	+	2
J. R. Miller	T. 2 S., R. 1 E., sec. 8		215	+	10
W. Noble	do		230	+	7
M. M. Miller	do	5	85	+	(?)160
Do	do	2	82	+	22
T. H. Pierce	do		80	+	20
C. West	do		172	+	10
J. Walker	do	1½	80	+	20
State fish hatchery	do	4		+	(?)130
Do	do	4		+	(?)100
Do	do	2	80	+	40
A. Gillard	do		310	+	17
H. Brinton	do	2		+	30
J. R. Hansen	T. 2 S., R. 1 E., sec. 9		120	+	6
L. B. Howard	do	2	148	+	18
A. Scott	do	2	96	+	20
H. Bagley	do	2	275–250	+	
Do	do	3	60	+	(?)100
W. Reynolds	do	2	100–103	+	43
F. Brinton	do		92–96	+	25
C. Bagley	do	1½	100	+	20
Do	do	2		+	30
R. Anderson	T. 2 S., R. 1 E., sec. 10		14	−	([a])

[a] Dry 9 months in year.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
A. Olander	T. 2 S., R. 1 E., sec. 15		18	− 16	
J. Spillet	do		15	− 10-11	
J. Smith	T. 2 S., R. 1 E., sec. 16		20	− 4-17	
J. Hemmert	do	2	78	− 40	
S. Neilson	do		18-20	− 8-10	
S. F. Smith	do		20	− 10	
A. L. Hansen	do		22	− 11	
J. W McHenry	do		18	− 12	
J. Hobbs	do		113	− 9	
J. Furgeson	do		60	+	17
I. Furgeson	do		60	+	
O. Headman	do		92	−	
J. Brighouse	T. 2 S., R. 1 E., sec. 17	1¼	58	+ 16	30
H. V. Ballard	do	2	83	+ 8	50
G. Peterson	do		14	− 9	
District school	do		250	− 12	
R. Brown	do		40	+ 8	
R. M. Ballard	do	1¼	46	+	35
Mrs. Shumann	do	2	50-60	+	20
H. E. Howe	do		60	+	22
D. A. Rauser	do		45	+	60
J. T. Erickson	do	2	175	+	2
F. C. Howe	do	2	90	+	35
Do	do	2	190	+	35
J. B. Thompson	do	1¼	75	+	45
Do	do	2	80	+	60
E. Taylor	T 2 S., R. 1 E., sec. 18		125	−117	
E. Gillen	do	2	20-30	−	
H. Berger	do	3	90	− 10	
C. Turner	do		70-80	− 4-13	
H. Chambers	do	2	200	− 10	
J. Jones	do	2	22	−	
J. H. Wheeler	do	2	75-100	+	20
South Cottonwood Ward.	do	2	75-100	+	40
Do	do	3	110	+	60
Mrs. J. Clark	do		18	− 4	
M. Sibbs	T. 2 S., R. 1 E., sec. 19	2	50	−	
N. Nelson	do		22	− 8	
C. Atkinson	T. 2 S., R. 1 E., sec. 20		10	−	
H. Wheeler	do		12	−	
C. B. Walder	do		22	−	
C. J. Wright	do		10	−	
W. Barrett	T. 2 S., R. 1 E., sec. 21		16	−	
J. E. Brown	do		13	−	
H. C. L. Russell	do		50	− 30	
J. W. Fawlke	T. 2 S., R. 1 E., sec. 22		6	−	
A. Fawlke	do		12	−	
S. Jones	T. 2 S., R. 1 E., sec. 26		80	− 55	
A. D. Brown	T. 2 S., R. 1 E., sec. 27		96	− 93	
(a)	T. 2 S., R. 1 E., sec. 28		125	−	
W. Baggas	T. 2 S., R. 1 E., sec. 29		18	−	
D. M. Griffin	do		22	−	
J. A. Wagstaff	do		35	−	

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
N. Morquist	T. 2 S., R. 1 E., sec. 29		30	− 26-27	
M. Holmes	T. 2 S., R. 1 E., sec. 30		35		
H. Chambers	do	2	200	− 7-10	
J. Jones	do	2	22	−	
O. G. Nelson	T. 2 S., R. 1 E., sec. 31		40-50	− 25-34	
C. G. Johnson	do		29-30	− 26	
G. L. Rosengren	do		51	− 41	
H. M. Pearson	do		90	− 60	
A. Neilson	do		53	−	
H. Larsen	do		26	−	
L. Jacobson	do		15	−	
W. Dugger	T. 2 S., R. 1 E., sec. 32		100	− 75	
A. Hansen	do		14	−	
E. E. Osbund	do		200	−200	
H. C. Monten	T. 2 S., R. 1 E., sec. 33		22	−	(a)
J. F. Proctor	T. 2 S., R. 1 E., sec. 34		40	−	
W. Rasmanson	T. 2 S., R. 1 E., sec. 35		50	−	Dry.
H. Covert	do		40	− 26	
Clark	T. 2 S., R. 1 W., sec. 1	2	40	+	20-35
J. M. Wood	do		100	+	40
E. Erickson	do		287	+	2
Lumston	do	2	140	+	22
(b)	do	2	90	+	25
Gleason	do		65	+	8
J. Hays	do		280	−	
J. Harper	T. 2 S., R. 1 W., sec. 2		372	− 18	
J. M. Mantell	do		240	+	6
J. Mackey	T. 2 S., R. 1 W., sec. 3		212	− 10	
Barker	do		260	− 25	
(b)	T. 2 S., R. 1 W., sec. 6		56	−	
Parker	T. 2 S., R. 1 W., sec. 8	3	157	− 37	
School	do		120	− 60	
Snider	do	3	150	− 50	
McAllister	T. 2 S., R. 1 W., sec. 9	3	110	−	
H. McKay	T. 2 S., R. 1 W., sec. 10	3	141	− 40	
H. Harker	T. 2 S., R. 1 W., sec. 11	3	315	+	35
W. H. Hague	do		222	− 15	
P. Swendsen	do	2	323	+	5
B. Williams	do	3	85	−	
G. Bueger	T. 2 S., R. 1 W., sec. 12	3	77	− 36	
Western Pickling Co	do		100	+	40
S. Benson	do	2	350	+	15
D. Adamson	do	2	249	+	20
Creamery	do	2	117	+	20
A. E. Erickson	do	2	345	− 8	
J. C. Cahoon	T. 2 S., R. 1 W., sec. 13	3	180	−	
Mrs. A. J. Plummer	do	3	60	− 30	
(b)	do		9½	− 6½	
M. Bishop	do	2	50	− 10	
E. B. Tripp	T. 2 S., R. 1 W., sec. 14	3	80	− 40	
A. S. White	do		22	− 12	
R. P. Binghurst	do	2½	175	− 6	
Jones	do	2	180	+	12

[a] Dry in winter. [b] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
J. Anderson	T. 2 S., R. 1 W., sec. 15		117	−50	
School	do		165	−50	
W. Diamond	T. 2 S., R. 1 W., sec. 22	3	345	−110	
M. Parker	do		225	−40	
M. Hansen	do		140	−90	
(a)	T. 2 S., R. 1 W., sec. 23		185	−24	
C. Erickson	T. 2 S., R. 1 W., sec. 24		30	−12	
E. Bateman	T. 2 S., R. 1 W., sec. 25	3	251	−	
(a)	do		20	−16	
Bingham School	do	3	325	−60	
J. B. Wright	T. 2 S., R. 1 W., sec. 26	3	230	−40	
E. Gardner	do		180	−20	
(a)	T. 2 S., R. 1 W., sec. 27		100	−30	
Cooper	do	3	254	+	2
W. D. Runsal	do		137	−33	
A. L. Cooley	T. 2 S., R. 1 W., sec. 30		28	−	
Olsen	T. 2 S., R. 1 W., sec. 33		178	−20-30	
Cannon Farm	T. 2 S., R. 1 W., sec. 34	3	1,000	−30	
R. Egbert	do	6	52	−24	
P. T. Rundquist	do	3	80	−18	
M. Pusler	T. 2 S., R. 1 W., sec. 35	3	217	−	
J. Peterson	do		127	−53	
N. L. Gardner	do	3	309	−25	
G. Hunt	T. 2 S., R. 1 W., sec. 36		21	−17	
S. M. Wilmore	do	3	225	−8	
N. Nelson	do		190	−75	
(a)	do		50	−	
P. Jansen	do		30	−17	
P. J. Wolff	T. 2 S., R. 2 W., sec. 11		174		
Olsen	T. 2 S., R. 2 W., sec. 27	3	150	+	
H. Brown	T. 3 S., R. 1 E., sec. 2		38-40	−	
W. L. Bateman	T. 3 S., R. 1 E., sec. 5		14-16	−6	
E. Johnson	T. 3 S., R. 1 E., sec. 6		40	−	
C. Peterson	do		28	−25	
A. Yelter	T. 3 S., R. 1 E., sec. 7		75	−70	
H. P. Hansen	T. 3 S., R. 1 E., sec. 8		56	−45-52	
P. Anderson	T. 3 S., R. 1 E., sec. 9		125		Dry.
R. Despain	T. 3 S., R. 1 E., sec. 11		16		Dry.
C. Williams	T. 3 S., R. 1 E., sec. 17		30	−28	
F. Olsen	T. 3 S., R. 1 E., sec. 18		40	−24	
P. A. Yastrop	T. 3 S., R. 1 E., sec. 19		80	−	
J. P. Jenson	do		95	−	
E. N. Fish	T. 3 S., R. 1 E., sec. 21		34		Dry.
J. L. Johnson	T. 3 S., R. 1 E., sec. 22		65	−	
J. W. Smith	T. 3 S., R. 1 E., sec. 28		10	−	
H. Pearson	T. 3 S., R. 1 E., sec. 29		18	−	
J. Tarry	do		18-20	−	
N. Brown	do		16	−	
J. R. Stocking	do		42	−	
A. J. Wilson	T. 3 S., R. 1 E., sec. 32	4	70	−62	
J. R. Allen	do		24	−18	
J. Ennis	do		41	−35	
J. Boulter	T. 3 S., R. 1 E., sec. 33		22	−17	
F. B. Ladler	do		66		(b)

a Owner's name unknown. b Dry in winter.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
P. Swindsen	T. 3 S., R. 1 W., sec. 1	2	323	+	5
E. Densley	do	3	200	−40	
C. Densley	do		30		
D. Densley, jr	do	3	412	−58	
J. F. Palmer	T. 3 S., R. 1 W., sec. 2	3	236	−43	
H. Gardner	T. 3 S., R. 1 W., sec. 3		250	−20	
J. A. Egbert	do		212	−40	
J. Goff	T. 3 S., R. 1 W., sec. 12	3	137	−	
B. Wellington	T. 3 S., R. 1 W., sec. 13	3	156	−45	
A. J. Holt	T. 3 S., R. 1 W., sec. 15	3	255	−85	
School	do		500	−75	
B. W. Osborne	T. 3 S., R. 1 W., sec. 23	2	50		12–15
W. R. Wellington	do	1½	28		12–15
C. Erickson	T. 3 S., R. 1 W., sec. 24		30	−12	
E. Atwood	do	3	127	−	
R. Carlson	do		28	−	
A. Yoblong	T. 3 S., R. 1 W., sec. 25		15	− 4	
J. O. Smith	do	3	133	−40	
Creamery	T. 3 S., R. 1 W., sec. 26	2	90	+12	
G. H. Donzy	T. 3 S., R. 1 W., sec. 27	3	225	−60	
C. H. Roberts	T. 3 S., R. 3 W., sec. 26	3	102	−	
I. Langton	T. 4 S., R. 1 E., sec. 5	2	400	+	3
G. Newbold	do		40	−	
G. Sproul	do	2	125	+	
L. Andrews	T. 4 S., R. 1 E., sec. 6		20	−10	
J. Ennis	T. 4 S., R. 1 E., sec. 32		41	−35	
H. J. Allen	do		15	−	
W. H. Garfield	T. 4 S., R. 1 E., sec. 33		42	−	
W. Crane	do		21	− 8	
Alpine	T. 4 S., R. 1 E., sec. 24		25–80		
W. L. Parry	T. 4 S., R. 1 W., sec. 3		30		
M. Densley	do	3	99½	−40	
J. Stedman	do	3	130	−40	
J. Beveridge	T. 5 S., R. 1 E., sec. 4		32	−20	
Lehi Junction	T. 5 S., R. 1 E., sec. 5		15–50	−10–40	
I. Anderson	T. 5 S., R. 1 E., sec. 7	2	134	+25	
Thomas College	do	1½	125	−	
J. Wanless	do	1½	125	−	
G. Jacobs	do	1½	90–100	+	12
Do	do	2	193	−	
D. J. Thurman	do	2	90–100	+	55
H. T. Davis	T. 5 S., R. 1 E., sec. 8		12	−	
G. Gerney	do	1½	145	− 8–10	
T. R. Jones	do	1½	75	−	
B. W. Brown	do		12	−	
J. Gough	do		20	−	
P. Austin	T. 5 S., R. 1 E., sec. 9	2	145	−22	
(a)	do	2	130	+	5
J. Brown	do	1½	135	−	
(a)	do	2	300	+	4
San Pedro, Los Angeles and Salt Lake R. R.	do	2	330	+	23
Do	do	1½	330	+	35
Do	do	3	300	− 8	
Do	do	1½	140	−	

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
W. Hunger	T. 5 S., R. 1 E., sec. 9	2	145	− 2	(?)25
Rhodes	do	1½	140	+	9
Wing	do	1½	158	−	
Anderson	do	2	132	+	20
Gilchrist	do	1½	130	− 6	
Barney	T. 5 S., R. 1 E., sec. 10	1½	145	+	20
D. Wagstaff	T. 5 S., R. 1 E., sec. 14	2	270	−	
A. L. Thornton	do	2	201	+	2
American Fork, city well.	do	3	460	−25	
A. Green	T. 5 S., R. 1 E., sec. 15		160	+	
J. B. Greene	do	2	160	+	40
J. Stewart	T. 5 S., R. 1 E., sec. 16	2	140	+	
Broadbent	do	2	150	+	10
A. K. Thornton	do	3	543	− 4½	
T. J. Chipman	do	2½	263	− 2	
J. Peters	do	6	33	−	
A. Field	do	1½	162	+	5
Mrs. K. Fox	do	2	130	+	10
(a)	do	2	90	+	10
(a)	do	2		+	15
(a)	do	2	90	+	20
(a)	T. 5 S., R. 1 E., sec. 17		147		
O. Ellington	do	1½	150	+	
E. A. Bushman	do	2	350	−	
Anderson	do	2	132	+	20
D. J. Thurman	do	2	150	+	10
J. Donaldson	do	2	143	+	20
J. Stewart	do	2	140	+	
P. Jacobs	do	1½	140	+	5
J. Woodhouse	do	1½	164	−	
M. Evans	do	2	200	+ 3	(?)100
Rio Grande Western Rwy.	do	3	165	+30	50
G. Webb	T. 5 S., R. 1 E., sec. 18	2	195	+ 3	40
S. R. Taylor	do	2	156	+10	
W. H. Chipman	T. 5 S., R. 1 E., sec. 23	2	147	+	(?)150
Do	T. 5 S., R. 2 E., sec. 11	2	135	+46	(?)200
B. Willis	T. 5 S., R. 2 E., sec. 18	2	160	+	
M. Evans	do	2		+	30
(a)	T. 5 S., R. 2 E., sec. 19	2		+	20
J. D. Godey	do	2	290	+	
S. E. Davis	do	2	150	+	80
W. Howe	T. 5 S., R. 2 E., sec. 20	2	200	+	20
Clarke	do	2	40	+	
Lott	T. 5 S., R. 2 E., sec. 21	2	100	+	60
(a)	T. 5 S., R. 2 E., sec. 23	2	264	+	10
Elgin creamery	do	3		+	
A. F. Adams	do	3	280	+	15
American Fork City	do	3	280	+	
W. Anderson	T. 5 S., R. 2 E., sec. 25	1½		+	10
W. D. West	T. 5 S., R. 2 E., sec. 29	2	64	+	15
Do	do	2	70	+	
(a)	do	2	74	+	35-50
Wadley	do	2	200	−33	
W. D. West	do	2	70	+18	

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
D. M. Smith	T. 5 S., R. 2 E., sec. 29	2	115	+20	45
(a)	T. 5 S., R. 2 E., sec. 32	2	150	+	
(a)	do	2	80	+	40
L. Olsen	do	2	160	+	90
F. Newman	do	2	150	+15	
Do	T. 5 S., R. 2 E., sec. 35	2	90	+	25
Pastures	do		100	+	
P. H. Aldred	T. 5 S., R. 1 W., sec. 1		100	+	80
I. Fox	T. 5 S., R. 1 W., sec. 12	2	100	+ 7 ins.	
Salt Lake City (about 130 wells).	do	2–6	100	+30	(?)2,000
J. M. Roberts	T. 5 S., R. 1 W., sec. 13	2	258	+	32
(a)	do	2	112	+	
M. Norman	T. 5 S., R. 1 W., sec. 24	2	160	+14	
I. Cole	T. 6 S., R. 2 E., sec. 5	2	210	+	
J. S. Johnson	do	2	130	+	
H. Gammon	T. 6 S., R. 2 E., sec. 7	3	110	+	(?)260
H. Gillies	do	2	112	+11	
D. A. Gillis	T. 6 S., R. 2 E., sec. 8	2	110	+	(?)100
J. K. Parcell	T. 6 S., R. 2 E., sec. 10		72	−67	
N. Knight	T. 6 S., R. 2 E., sec. 14		110	−	
Colorado Fish Co	do	3	250	−80	
N. J. Knight	do		60	−40–55	
W. Knight	do	2	300	−	
J. S. Park	T. 6 S., R. 2 E., sec. 15		72	−62	
A. N. Holdaway	T. 6 S., R. 2 E., sec. 17	2–3	120–140	+ 1–10	(?)1-200
M. Holdway	do	2	100	+	30
B. Larsen	T. 6 S., R. 2 E., sec. 18	3	100	+12	
Wride & Allen	do	2	110	+	(?)100
G. A. Slumway	T. 6 S., R. 2 E., sec. 21	2	104	+	25
J. A. Loveless	T. 6 S., R. 2 E., sec. 23		52	−50	
A. L. Mechum	T. 6 S., R. 2 E., sec. 24		40	−36	
D. C. Daniels	T. 6 S., R. 2 E., sec. 26	48	65	−60	
H. C. Scott	T. 6 S., R. 2 E., sec. 28	2	110	+	10
J. H. Clinger	do	1½	98	+	10
Creamery	T. 6 S., R. 2 E., sec. 34		125	+	
J. W. Park	do		110	+	
W. G. Williams	do	1½	130	+	
S. L. Aldred	T. 6 S., R. 2 E., sec. 35	2	210	−25	
W. Gammon	do		24	−	
P. H. Cluff	T. 6 S., R. 3 E., sec. 31		50	−40–45	
T. W. Whisble	T. 7 S., R. 2 E., sec. 1	2	217	+	48
J. A. Johnson	do	2	145	+	6
N. Lydian	T. 7 S., R. 2 E., sec. 2	2	145	+	
S. McFee	do	2	145	+	8
A. Holliday	do	2½	150	+10	
W. Cox	do	2	130	+	85
P. C. Bumrell	T. 7 S., R. 2 E., sec. 3	1½	135	+	25
Utah Sugar Co	do		110	+	
W. L. Camp	do	2	128	+	
N. A. Nelson	do		35	−	
R. A. Hills	T. 7 S., R. 2 E., sec. 4		50	−	
Provo resort	T. 7 S., R. 2 E., sec. 9	2	342	+	80
G. Baum	T. 7 S., R. 2 E., sec. 10		12	− 4	
W. D. Roberts	T. 7 S., R. 2 E., sec. 11	2	184	+	92

[a] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
Westron	T. 7 S., R. 2 E., sec. 11	2	180	+	
W. B. Johnson	do	1½	160	+	15
M. Christensen	do	2	168-178	+	10
B. Johnson	do	2	150	+	45
W. Carter	do	2	170	+	40
Rio Grande Western Rwy.	T. 7 S., R. 2 E., sec. 12	3	175	+	(?)120
San Pedro, Los Angeles and Salt Lake R. R.	do	3	192	+35	(?)150
W. R. Pike	do	1½	248	+12	40
Do	do	1¼	198		36
W. J. Woodhead	do	2	168	+	60
H. Manney	do		168	+	60
Hospital	do		180	+	
W. Scott	do	2	150	+	55
S. W. Sharp	do	2	197	+	30
Farris Bros	do		185	+	60
S. Copp	do	2	175	+	9
Watkins & Taylor	do		300	+	2
(a)	T. 7 S., R. 2 E., sec. 14	1½	145	+	20
A. B. Johnson	do		170		
G. T. Peay	T. 7 S., R. 2 E., sec. 16	2	137	+ 5	30
A. W. Hanrer	T. 7 S., R. 3 E., sec. 6	2	140	+ 2	40
T. E. Thurman	do	1½	333	+20	35
J. Anderson	T. 7 S., R. 3 E., sec. 8	2	150	+20	15
Utah Co. Infirmary	T. 7 S., R. 3 E., sec. 17	3	270	+	70
H. M. Dougal	T. 7 S., R. 3 E., sec. 29	2	180	+10	40
Do	T. 7 S., R. 3 E., sec. 30	2	220	+ 4	20
Clubhouse	do	1½	299	+	5
Do	do	2	128	+	10
P. Boyer	T. 7 S., R. 3 E., sec. 31	2	150	+	18
Rio Grande Western Rwy.	T. 7 S., R. 3 E., sec. 32	3	220	+30	80
(a)	do	1½	232	+	15
J. B. Stevenson	T. 7 S., R. 3 E., sec. 33	1½	101	+	12
D. Wheeler	do	2	131	+	25
D. Clark	do	2	240	+	
A. Cox	do	3	230	+18	(?)120
W. Findley	do	2	135	+	25
(a)	do	2	115	+	70
A. Oakley	do	2	128	+	30
(a)	do	2	105	+	30
J. McCurdey	do		22	−	
(a)	do	1½	120	+	20
T. L. Mendenhall	do	2	245	+	45
S. Fuller	do		25	−	
M. Dougal	do	1½	230	+	10
E. P. Brinton	do	2	130	+	20
McKenzie	do	1½	132	+	10
Daley	do	1½	145	+	9
F. W. Phillips	do	2	217	+	65
(a)	do	2	138	+	30
W. Brookes	T. 8 S., R. 1 E., sec. 11	1½	160		10
(a)	do	1½	100	− 4	
(a)	T. 8 S., R. 1 E., sec. 24	1½		+	7

[a] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
J. D. Evans	T. 8 S., R. 2 E., sec. 2	2	438	+	25
E. L. Oltison	T. 8 S., R. 2 E., sec. 4	2	366	+	72
H. Otis	do	1½	380	+	20
C. Barney	do	2	175	+10	20
(a)	do	1½	112	+	10
(a)	do	2	175	+	12
J. Hall	T. 8 S., R. 2 E., sec. 7	2	225	+	
J. S. Bellows	T. 8 S., R. 2 E., sec. 8	1½	400	+12	8-25
W. J. Soloman	do	2	230	+10	35
R. Hunter	do	2	350	+	8
J. E. Creer	T. 8 S., R. 2 E., sec. 9	2	400	+	
P. Poulsen	do	2	390	+10	40
P. Neilson	T. 8 S., R. 2 E., sec. 10	1½	142	+	
E. P. Thomas	do	3	430	+	15
A. Green	T. 8 S., R. 2 E., sec. 12	2	280	+	10
Do	do	2	260	+	5
Creamery	T. 8 S., R. 2 E., sec. 13	2	220	− 4	
San Pedro, Los Angeles and Salt Lake R. R	do	2	405	+	36
A. T. Money	T. 8 S., R. 2 E., sec. 14	2	380	+	16
R. W. Money	do	3	423	+	60
W. R. Simmons	T. 8 S., R. 2 E., sec. 15	2	374	+	1
A. M. Furgeson	do	6	380	+	60
P. E. Nelson	do	2	400	+	30
Irrigation Co	do		500	+	60
Lake Shore Canal	do	3	373	+	(?) 118
E. M. Robertson	T. 8 S., R. 2 E., sec. 16	1½	160	−	
N. P. Hansen	do	2	380	+	3
(a)	T. 8 S., R. 2 E., sec. 18	2	450	+	
(a)	do	2	412	+	30
G. McClellan	T. 8 S., R. 2 E., sec. 19	2	387	+	15
Do	do	2	170	+	6
Do	do	1½	130	+	2
Do	do	1½	45	+	3
N. Thompson	T. 8 S., R. 2 E., sec. 20	2	475	+	10
D. L. Hoff	T. 8 S., R. 2 E., sec. 21	2	333	+	16
E. Ludlow	do	1½	250	+	8
C. Howe	do	2	560	+	20
T. Cahoon	do	2	400	+	10
(a)	T. 8 S., R. 2 E., sec. 22	1½	286	+	
(a)	do	1½		+	6
O. Christensen	T. 8 S., R. 2 E., sec. 23	2	385	+	8
D. C. Markham	do	2	360	+	35
G. Hales	do	3	250	− 6	
(a)	T. 8 S., R. 2 E., sec. 25	2	137	+	35
N. P. Jensen	T. 8 S., R. 2 E., sec. 26	2	318-320	+	64
B. Isaac	do	2	390	+	14
(a)	T. 8 S., R. 2 E., sec. 27	2		+	60
P. Thomas	do	2	425	+	35
F. Malley	T. 8 S., R. 2 E., sec. 28	1½	385	+	5
Howe	do	2	415	+	
G. Howe	T. 8 S., R. 2 E., sec. 29	2	450	+	
(a)	do	2	175	+	8
Stewart's ranch	do	1½		+	20
Do	do	1½		+	10

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
Stewart's ranch	T. 8 S., R. 2 E., sec 29	2		+	5
C. Hickman	do	2	172	+	15
S. P. Lorensen	do	2	163	+	25
P. J. Lundale	T. 8 S., R. 2 E., sec. 32	1½	175	+	1
J. Howe	T. 8 S., R. 2 E., sec. 33	2	200	+	1
J. J. Hansen	do	2	380	+	20
G. Staley	do	2	185	+	20
Do	do	2	380	+	35
W. O. Creer	T. 8 S., R. 2 E., sec. 35	1½	20	+	10-25
Creamery	T. 8 S., R. 3 E., sec. 4	2	144	+	30
J. Anderson	T. 8 S., R. 3 E., sec. 5	2	145	+	
M. C. King	T. 8 S., R. 3 E., sec. 7	2	170	+	30
Do	do	2	154	+	12
[a]	T. 8 S., R. 3 E., sec. 8	1½	30	+	2-3
Sugar factory	do	2	123	+	10
T. B. Jones	T. 8 S., R. 3 E., sec. 21		22	−15	
[a]	T. 8 S., R. 3 E., sec. 30	1½	140	+	2
H. A. Harlan	do	1½	30	+	1½
J. P. Holt	do	1½	100	+	1½
J. G. Robertson	do			+	
G. LeBaron	T. 9 S., R. 1 E., sec. 7			+	
McBeath	T. 9 S., R. 1 E., sec. 12	2	360	+	27
J. Webb	T. 9 S., R. 1 E., sec. 13	1½	247	+	
F. Rouse	T. 9 S., R. 1 E., sec. 32	2	180		8
J. E. Gardner	T. 9 S., R. 2 E., sec. 1	1½	290	−	
[a]	do	1½	155	+	
[a]	T. 9 S., R. 2 E., sec. 2	1½	200	+	
[a]	do	2	200	+	
[a]	T. 9 S., R. 2 E., sec. 3	2	160	+	30
[a]	do		375	+	
[a]	do	2	228	+	(?) 125
S. Douglas	T. 9 S., R. 2 E., sec. 5	2	50	+ 15	
Do	do		130		30
Dixon Bros.	do	2	300	+	(?) 100
P. Windward	do	2	140	+ 1	55
T. E. Daniels	T. 9 S., R. 2 E., sec. 6	2	116	+ 20	
C. Long	do	2	160	+	37
D. LeBaron	T. 9 S., R. 2 E., sec. 7	2	217	−	
[a]	T. 9 S., R. 2 E., sec. 10		438		3
A. Bingham	T. 9 S., R. 2 E., sec. 11	1½	196	+	15
Do	do	2	275	+	8
Creamery	do		225	+	
C. Hanks	do	2	175	+	10
A. Burke	do	2	296	+	25
J. Sheen	do	2	279		35
O. R. Thomas	T. 9 S., R. 2 E., sec. 29		20	−16½	
H. Boyle	T. 9 S., R. 2 E., sec. 30	2	90-126	+	15-30
J. Job	T. 9 S., R. 1 W., sec. 25	1½	50- 60	+	12
Do	T. 9 S., R. 1 W., sec. 26	1½	220	+	
W. M. Phillippi	T. 9 S., R. 1 W., sec. 33	2	165	−125	
[a]	T. 9 S., R. 1 W., sec. 35	2	200	+	½
Rudd estate	T. 9 S., R. 1 W., sec. 36	2	58	+	2
A. Steele	T. 10 S., R. 1 E., sec. 6		85	+	7-8
E. Hawkins	T. 10 S., R. 1 E., sec. 17	2	130	− 80	
H. Johnson	T. 10 S., R. 1 W., sec. 2		407	− 9	

[a] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
W. M. Phillippi	T. 10 S., R. 1 W., sec. 4	2	168	–	....
W. C. Albertson	T. 10 S., R. 1 W., sec. 9	2	178	–	....
J. Riley	do	2	307	–100	....
Do	do	2	300	–	....
Baxter	do	2	420	–	....
P. Okleberry	T. 10 S., R. 1 W., sec. 11	2	77	– 3	....
(a)	T. 10 S., R. 1 W., sec. 12	....	412	–	....
Creamery	do	....	70	– 4	....
Rio Grande Western Rwy	do	....	334	– 4	....
W. Finch	T. 10 S., R. 1 W., sec. 14	2	160	–	....
L. E. Thomas	T. 10 S., R. 1 W., sec. 15	....	8	–	....
Goshen Wells	do	1½	50	– 3	....
Do	do	2	70	– 20	....
A. Lewis	do	2	60	–	....
H. L. Cook	do	2	53	– 7	....
Allen	T. 10 S., R. 1 W., sec. 21	2	116	– 86	....
Rowe	T. 10 S., R. 1 W., sec. 30	2	238	–222	....
(a)	T. 10 S., R. 1 W., sec. 33	2	138	–	....

[a] Owner's name unknown.

INDEX.

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Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

APRIL, 1906.

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CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY REPORT

ON THE

GEOLOGY AND UNDERGROUND WATERS OF THE ROSWELL ARTESIAN AREA NEW MEXICO

BY

CASSIUS A. FISHER

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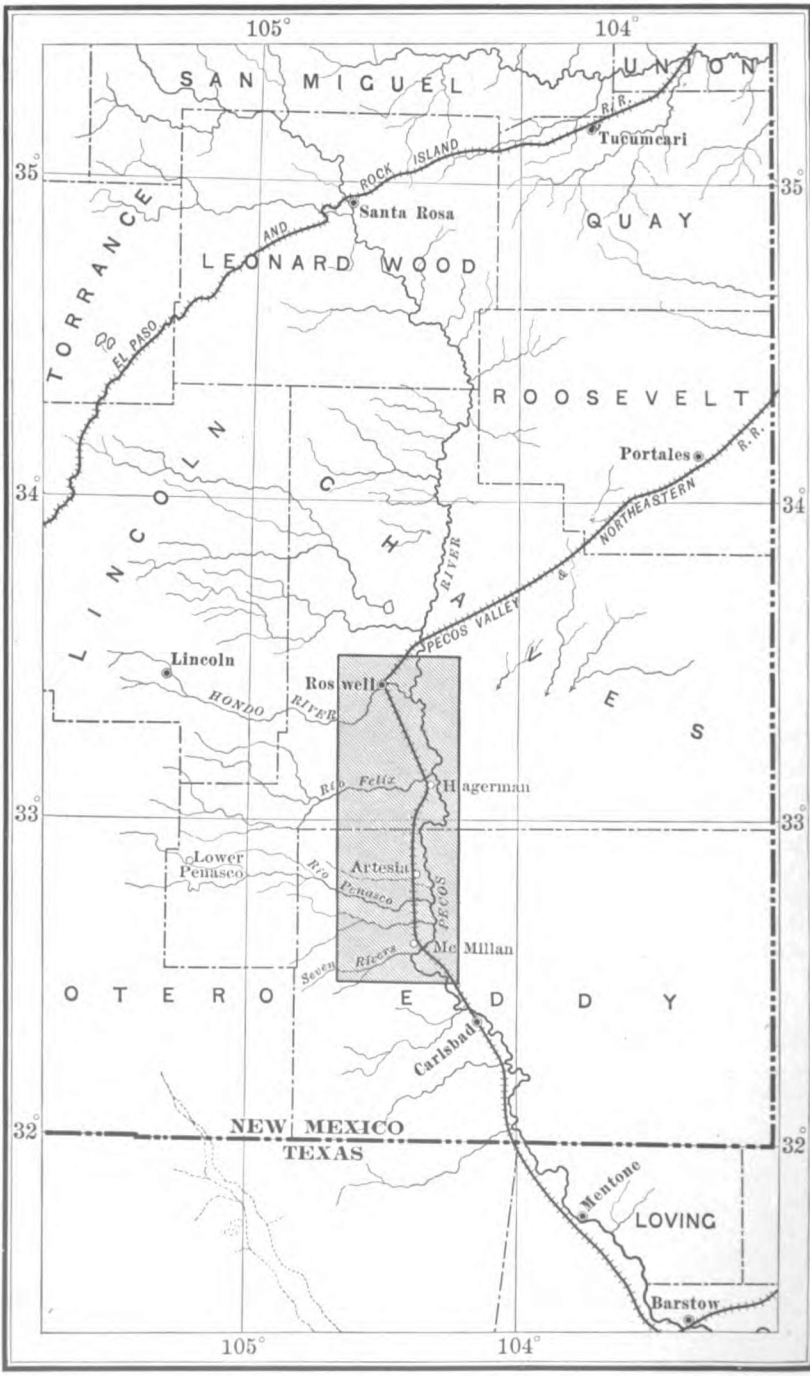


MAP SHOWING GENERAL LOCATION OF THE ROSWELL ARTESIAN AREA.

PRELIMINARY REPORT ON THE GEOLOGY AND UNDERGROUND WATERS OF THE ROSWELL ARTESIAN AREA, NEW MEXICO.

By CASSIUS A. FISHER.

INTRODUCTION.

The area to which this report relates is located in southeastern New Mexico. It comprises about 1,800 square miles lying along Pecos River and extending from a point 5 miles north of Roswell to below the mouth of Seven Rivers, as shown in Pl. I. In addition to the discussion of the artesian waters, the report includes a brief description of the geology of the sedimentary rocks, their structure, and their relation to the underground waters. The area of flowing wells is indicated on the map, Pl. VI, and records of representative wells are given, which are intended to illustrate the character and succession of the water-bearing beds) Information respecting surface waters available for domestic and irrigation purposes and a brief description of the climatic and agricultural features of the region are also given.

The investigation was conducted under the direction of Mr. N. H. Darton.

The writer was assisted in the field by Messrs. E. M. Mitchell and E. Patterson, and these gentlemen obtained a portion of the well data upon which this report is based. The systematic measurement of well pressures was carried on under the direction of Mr. W. M. Reed, district engineer of the Reclamation Service, who has done much to promote the work. The chemical analyses of the surface and artesian waters have been kindly furnished by Mr. E M. Skeats, of El Paso, Tex., and the paleontological collections have been examined by Dr. G. H. Girty. I am indebted to Messrs. Hagerman, Goodart, Phillips, Hortenstein, Spurlock, Hale, and others for information concerning artesian irrigation.

An excellent report on the soils of the Roswell basin by Messrs. T. H. Means and F. D. Gardner was used in the preparation of this report.

TOPOGRAPHY.

Relief.—The topographic features of the Roswell basin present little variety. Across the east side of the district there are irregular bluffs rising 200 to 300 feet above Pecos River, while to the west the surface rises gradually toward the high limestone plateau bordering the Capitan, Sierra Blanca, and Sacramento mountains. The region has an average elevation of 3,600 feet above sea level. The highest portion is along the west side of the district, where the altitude is about 4,000 feet. In the southeast corner the altitude is about 3,200 feet. Near the junction of the North and South forks of Seven Rivers there is a high bluff having a north-facing escarpment, which rises high above the valley of the South Fork, and on the north side of Eagle Draw is a small but prominent plateau.

Drainage.—The principal drainage channel is Pecos River, which enters from the north and flows in a southerly direction across the district. The flow is not large, but it carries a small amount of water during the entire year. There are a number of tributaries from the west, the largest being the Hondo, Felix, Penasco, and Seven rivers. Hondo and Penasco rivers, perennial streams throughout their upper courses, have their sources high on the

slopes of the Capitan, Sierra Blanca, and Sacramento mountains. The Felix and Seven rivers rise in the limestone plateaus lower down, and drain a much smaller area. Hondo River east of Roswell is joined on the north by North Spring and Berrendo rivers, and on the south side near its mouth by South Spring River. These streams are fed by springs, and they carry abundant water at all seasons. There are also several small intermittent streams which enter Pecos River. Those from the west are Gardners Arroyo, Fourmile Creek, Eagle Draw, Cottonwood Creek, Walnut Draw, and Zuber Hollow; those from the east are Comanche Draw and Long Arroyo.

Lakes.—At the heads of North and South Spring rivers and Middle and South Berrendo rivers are lakes of moderate size. These lakes are fed by a number of small springs, which derive their water mainly from the unconsolidated deposits underlying Hondo, Blackwater, and Eden valleys. Water rises to the surface in the lower courses of Felix River, Cottonwood Creek, Penasco River, Gardners Arroyo, and North and South Forks of Seven Rivers. In the vicinity of Lake Arthur, Hagerman, Greenfield, and Dexter, and north along the east side of the Northern canal there are lakes fed in part by springs and in part by seepage from the Northern canal.

On the east side of Pecos River, about 12 miles southeast of Roswell, are several deep lakes lying along the base of the gypsum bluffs, which are locally known as the "Bottomless Lakes." Dimmit Lake, the largest of these, is situated at the head of a short ravine about 2½ miles from Pecos River. Near the mouth of this ravine, on the north side, is Dee Lake, and along the base of the bluffs for some distance to the north several smaller lakes occur. The location of these lakes is shown on the geologic map, Pl. IV. They have probably been formed by flood water from the high slopes to the east, which, in flowing over the exposed gypsum ledges at the edge of the bluffs, has dissolved the gypsum and formed subterranean passages that now extend to some of the shallow artesian flows in Pecos Valley. A view of one of the "Bottomless Lakes" is shown in Pl. III, *A*. The water from some of these lakes is used for irrigation.

OUTLINE OF GEOLOGIC RELATIONS.

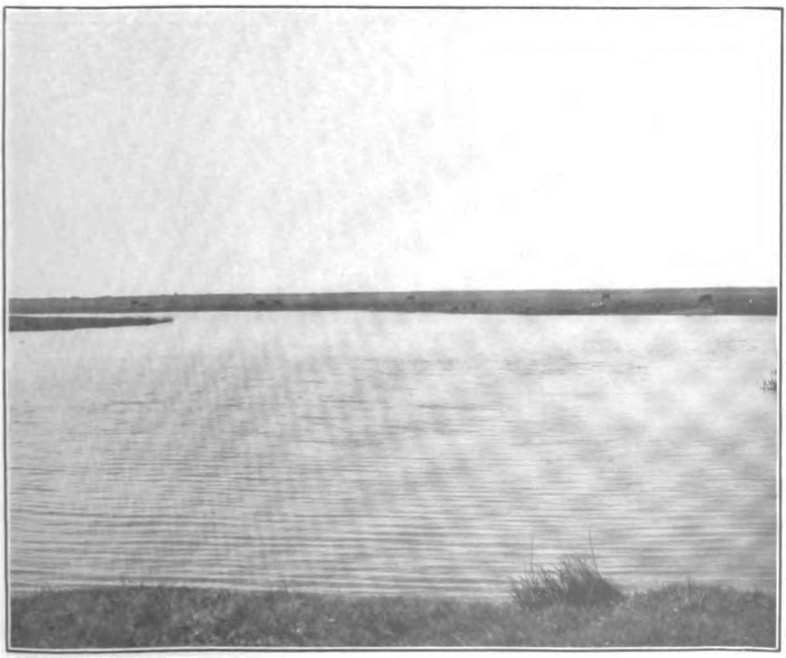
GENERAL STATEMENTS.

The rocks of the district comprise limestone, sandstone, clay, and gypsum which are believed to be of Permian age. Overlying these deposits throughout the Roswell basin are extensive sheets of sand, gravel, clay, and silt, probably of Quaternary age, which have been deposited in successive terraces between Pecos River and the high limestone slopes to the west. The so-called Permian series of this district consists of an upper red bed member of gypsum, red sand, limestone, and clay 600 to 800 feet thick, forming the high bluffs along the east side of Pecos River and underlying the recent deposits of Pecos Valley, and a lower member of massive limestone, clay, and gypsum of undetermined thickness, which constitutes high rugged slopes to the west. Overlying the red-bed division east of Pecos River is a reddish-brown sandstone about 100 feet thick, which may be of Cretaceous age. No subdivisions have been made of the probably Permian rocks in this region in the present reconnaissance.

PERMIAN (?) SERIES.

Red-bed division.—These rocks consist of alternating beds of gypsum, red sand, and clay, with an occasional layer of dark-gray, compact limestone. The gypsum predominates and usually occurs in beds about 10 feet thick. It is often found, however, in thinner layers, interbedded with clay and limestone. The red beds are provisionally placed in the Permian, although no fossils have been found in them. They are not shown separately on the geologic map (Pl. IV), but are represented with the underlying massive limestones. The upper part of the beds is well exposed in the bluffs along the east side of Pecos River, where a number of sections have been measured. These sections are as follows:

A. HEAD OF NORTH SPRING RIVER.



B. HEAD OF SOUTH SPRING RIVER.

A. VIEW OF "BOTTOMLESS LAKES," EAST OF PECOS RIVER.

B. ARTESIAN WELL AND RESERVOIR EAST OF SOUTH SPRING, NEW MEXICO.

Sections of gypsum bluffs along the east side of Pecos River, New Mexico.

	Feet.
East of Roswell:	
Alternating layers of gypsum and red sand, with an occasional layer of limestone	50
White gypsum	6
Red sand	6
White, thin-bedded gypsum	10
Red sandstone containing thin layers of limestone	24
White gypsum	5
Red sand	13
Gypsum	10
Red sand	3
Gypsum	8
Red sand	8
Gypsum	4
Greenish-gray sandstone	25
Gypsum	6
Total	178
At Dimmit Lake:	
Gray, sandy limestone	20
Alternating layers of gypsum and red and green clay, with an occasional bed of porous limestone	100
Gypsum	4
Red clay	2½
Gypsum	18
Alternating layers of gypsum and red clay	6
Gypsum	11
Alternating layers of gypsum and red sandstone	6
Gypsum	9
Red clay	1
Gypsum	10
Alternating layers of gypsum and red clay	15
Gypsum	5
Red clay	1½
Gypsum	10
Red clay	7
Alternating layers of gypsum and red clay	8
Gypsum	6
Red clay, with thin layers of gypsum	3
Gypsum	6
Total	249
Eight miles northeast of Artesia:	
Gray, compact limestone	5
Gypsum and red, sandy clay in alternate succession	65
Red, sandy clay	10
White, massive gypsum	15
Red, sandy clay	5
White gypsum	10
Gray limestone	5
Gypsum	18
Red clay	12
Gypsum	5
Total	150
About 2 miles southeast of the mouth of South Fork of Seven Rivers:	
Massive, gray limestone	35
Gypsum and red sandstone in alternate layers, with an occasional limestone ledge	50
Gypsum, thin-bedded porous limestone, and red sandstone arranged alternately, the gypsum predominating	150
Gypsum, with thin layers of gray limestone	50
Total	285

Limestone division.—The massive limestone beds underlying the so-called Permian red beds of this region consist mainly of gray, compact limestone, with layers of soft sandstone, clay, and gypsum. In the upper part the limestone is more or less thin-bedded and

porous, and contains many sandy layers. From these beds some of the strongest artesian flows in the Roswell basin are obtained. Limestone outcrops along the west side of the district, and farther to the west forms high rugged plateaus, extending toward the mountains. Fossils are not abundant in the formation, but in one locality northwest of Roswell a number were collected, which consisted mainly of *Schizodus* and *Pleurophorus*, preserved as casts. According to Doctor Girty the fauna and lithology of these specimens suggest the highest Carboniferous beds or the Permian of the Mississippi Valley in Texas.

To the east of the Roswell district the high plains are traversed by dikes of igneous rock. One of these dikes extends into the area in the northeast corner, but passes beneath the surface at a point about 5 miles east of Pecos River. Its location is shown on the geologic map (Pl. IV). The dike is about 35 feet wide, and consists of a light-colored rock, which is much decomposed on the surface.

Extending across the southeast portion of the area, from below Lake McMillan to the high bluffs east of Artesia, is a narrow zone in which the sedimentary rocks are more or less metamorphosed, so that in the crevices considerable mineralization has taken place. Copper is the principal mineral, occurring mainly as the carbonate and oxide. Some prospecting has been done in the hills south and east of Artesia, but no paying ore has been discovered.

CRETACEOUS (?) SYSTEM.

The sandstone overlying the Permian (?) red beds along the east side of the district is possibly, as above stated, of Cretaceous age. A few fossil plants were found in these beds, but they were too fragmentary to be determined. The distribution of the formation was not ascertained. It consists of massive, reddish-brown sandstone in beds of varying thickness, with an occasional layer of light-gray sandstone. The material is coarse grained and cross-bedded throughout, and often weathers into rounded forms. The following is a section of the sandstone near Petty's windmill, about 15 miles northeast of Roswell:

Section of sandstone overlying Permian (?) red beds near Roswell, N. Mex.

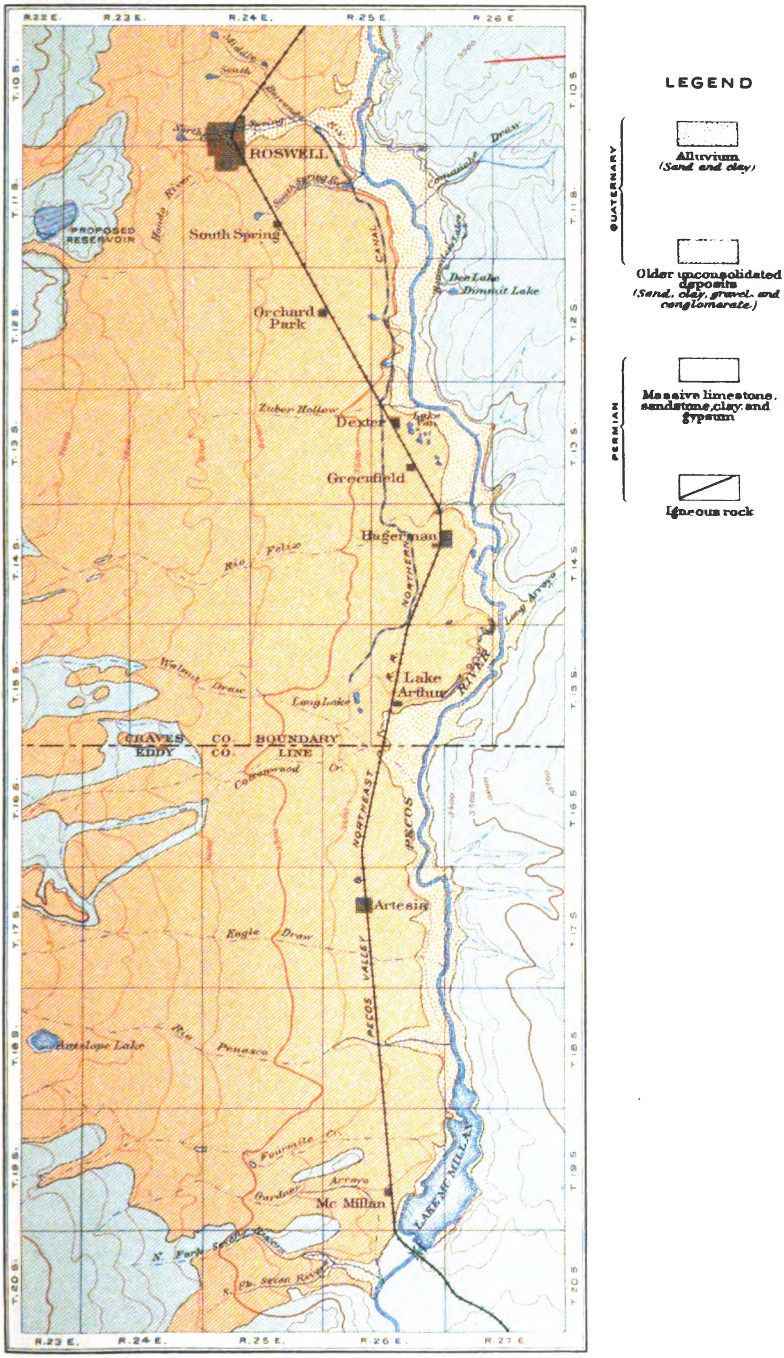
	Feet.
Reddish-brown, cross-bedded sandstone	40
Brown, massive sandstone	6
Lighter brown, massive sandstone, somewhat cross-bedded	10
Gray, coarse-grained sandstone	1
Reddish-brown sandstone	18

QUATERNARY SYSTEM.

The formations of the Quaternary period cover an extensive area in the Roswell basin, comprising approximately 1,200 square miles. They occupy the entire central portion of the basin, and extend far up the limestone slopes to the west. These deposits are mainly of two kinds—the alluvium of the river valleys and the unconsolidated material of higher levels.

Alluvium.—The alluvium is confined mainly to Pecos River Valley, although small areas occur along all the larger and many of the smaller streams. It is a light-colored, fine-grained material, consisting mainly of sand, gravel, and clay, with a small amount of organic matter. In the lower portions of the valley the soil contains much "alkali," often sufficient to render it unfit for cultivation. There are many small lakes along the river bottom, and the lowlands are generally swampy. On the east side of Pecos River, from a point opposite Dexter to beyond Comanche Draw, there are several springs, which have built cones of spring deposits 6 to 10 feet high.

Hondo, Felix, and Penasco rivers have built small flood plains along their lower courses which are perceptibly higher than the surrounding region. The alluvium along these streams varies somewhat in character, but it is generally of a light-gray color, and consists of gravel, sand, silt, and clay, covered by a fertile soil. The fertility is due to the presence of fine silt brought down by the flood waters from the high mountain rgeions. According



RECONNAISSANCE GEOLOGIC MAP OF THE ROSWELL ARTESIAN BASIN, SOUTHEASTERN NEW MEXICO

BY C. A. FISHER

Topography compiled from railroad data and barometer readings

Scale

2 0 2 4 6 8 10 miles

Contour interval 100 feet

1905

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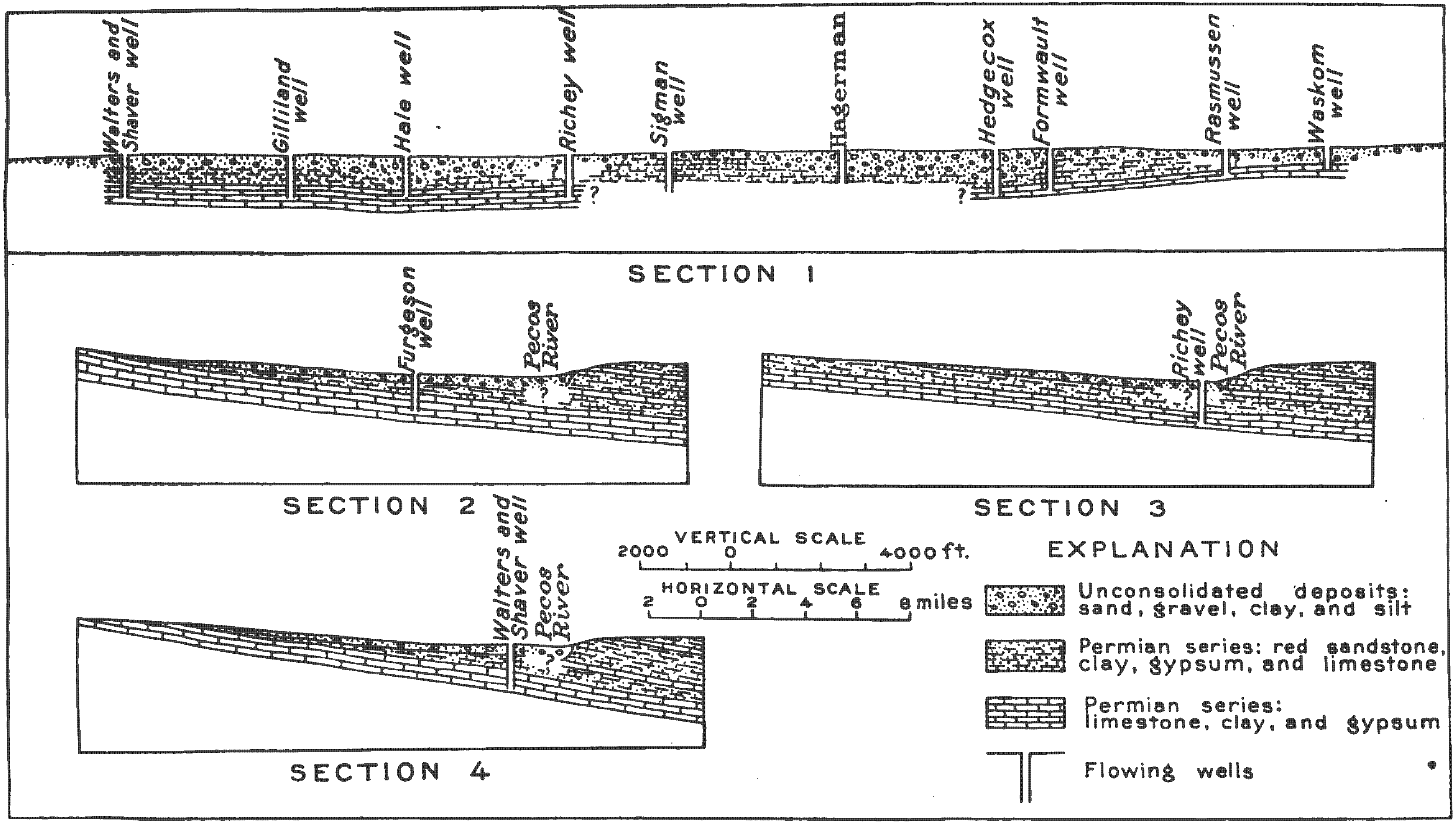


GEOLOGIC SECTIONS ACROSS THE ROSWELL ARTESIAN BASIN.

to Mr. T. H. Means the alluvium of Hondo Valley contains more plant food than that of the Nile in Egypt. The following analyses are taken from Mr. Means's report:[a]

Chemical composition of Hondo and Nile sediment.

Constituent.	Hondo mud (Skeats).	Nile mud (Mac-kenzie).	Constituent.	Hondo mud (Skeats).	Nile mud (Mac-kenzie).
Insoluble matter and silica	43.6	58.17	Soda		.62
Iron oxide and alumina	21.4	24.75	Sulphuric acid	1.96	.20
Oxide of manganese		.09	Phosphoric acid	.3	.21
Magnesia	2.1	2.42	Carbonic acid		1.55
Lime	5.7	3.31	Organic matter	9.8	8.00
Potash	1.19	.68	Nitrogen in organic matter	.32	.12

Unconsolidated deposits.—These deposits consist mainly of sand, gravel, and clay. The sand is of light-gray color, medium to fine grained, the clay more or less sandy, and the gravel a moderately coarse variety. The gravel is often firmly cemented by calcium carbonate, and local deposits of gypsum and a calcareous material known as "caliche" occur throughout the formation. According to well records the thickness of the formation varies considerably in different parts of the basin. In several deep wells around Artesia coarse gravels were encountered 500 to 700 feet below the surface. At Roswell and in the lower part of Hondo Valley unconsolidated sediments are 150 to 300 feet thick, and in Seven Rivers Valley they are probably thicker. In John Richey's well, 8 miles northeast of Artesia, a gravel bed, apparently the base of the unconsolidated sediments, was penetrated at a depth of 134 feet. At Sigman's well, near Lake Arthur, according to the driller's statement, the unconsolidated deposits are only a few feet thick, and about 3 miles northeast of Lake Arthur the red, sandy beds of the Permian (?) are exposed.

ARTESIAN WATER HORIZONS.

There are several artesian horizons in the formations underlying the Roswell basin. Flows of moderate volume are found in the sandstones of the upper member of the Permian (?) series and in the overlying unconsolidated deposits, but the strongest are from porous limestones interstratified with beds of sand, which constitute the upper part of the massive limestone division.

EXTENT OF ARTESIAN AREA.

The Roswell artesian basin is about 60 miles long and has an average width of 11 miles. At the north end it is relatively narrow, but to the south it widens somewhat. It comprises about 650 square miles, the greater part of which lies along the west side of Pecos River. The area of flow is shown on Pl. VI.

In the vicinity of Roswell the head of artesian water, as determined both by practical tests and by the pressures of a number of flows in the town of Roswell, is sufficient to raise water to an altitude of 3,586 feet above sea level, the exact elevation of the water level in the head of North Spring River. In order to ascertain the western limit of the area of flow south of Roswell a line of levels was surveyed, under the direction of Mr. W. M. Reed, district engineer, from the head of North Spring River as far south as Eagle Draw. From there to Seven Rivers the western boundary of the artesian basin was ascertained mainly from evidence of wells in the adjoining lowlands. It is possible that the artesian head increases to the west and that flows might be obtained higher up the slopes than is indicated on the artesian water sheet, especially in the valleys of Felix River, Cottonwood Creek, and Penasco River, but there appears to be no definite evidence of this. The eastern limits of the artesian area

[a] Means, T. H. and Gardner, F. D., Soil survey in the Pecos Valley: Field operations of Bureau of Soils, 1899, U. S. Dept. Agric., Rept. No. 64, 1900, p. 49.

are indicated by moderately high bluffs, which follow the general course of Pecos River across the entire district.

About 15 miles northeast of Roswell on the south side of Salt Creek are a number of springs that furnish considerable water. It is possible that shallow flowing wells would be obtained in the lowlands of Salt Creek Valley below these springs, but no investigation was made of this region. At Stockpens, about 13 miles northwest of Roswell and a short distance south of the mouth of Salt Creek, a deep test well was being sunk at the time this investigation was made. The boring had reached a depth of 900 feet without obtaining a flow, but it was the intention of the well owners to continue to a depth of 1,000 feet. The head of artesian water in the northern part of the Roswell basin, as calculated from the pressures of flows in the vicinity of Roswell, is not sufficient to bring water to the surface in wells at Stockpens.

There is a deep well at Portales, N. Mex., in which a flow was obtained at a depth of about 400 feet. A record of this well is as follows:

Record of well at Portales, N. Mex.

	Feet.
Soil	0- 4
Gypsum	4- 8
Red, sandy clay	8- 20
White limestone	20- 32
Red, sandy clay	32- 48
White limestone	48- 88
Red clay	88-188
"Flint rock"	188-189
Coarse gravel and sand	189-219
Red clay	219-297
White sandstone	297-309
White sand and clay in alternate layers	309-399

WELLS AND WELL PROSPECTS IN ROSWELL ARTESIAN BASIN.

GENERAL CONDITIONS.

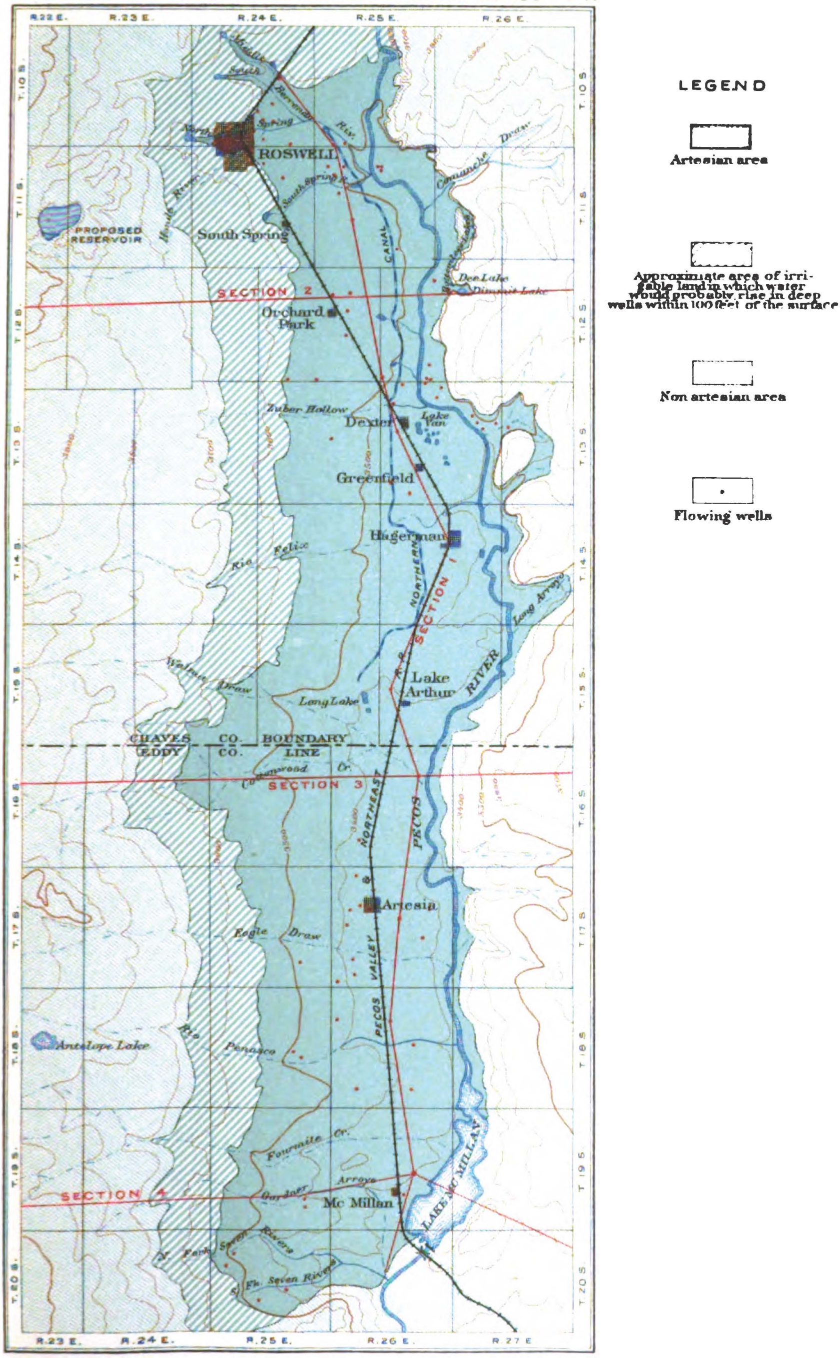
Flowing wells were first obtained in the Roswell basin about ten years ago and for a number of years thereafter development was confined chiefly to this immediate vicinity. During the last two years, however, strong flows have been obtained near Artesia, and at present this part of the basin is receiving the greatest development. Owing to the rapid progress in well sinking throughout the Roswell basin it is difficult to give a complete list of the flowing wells. Information of about 200 has been obtained, but it is probable that the total number at present exceeds 250. About half of this number are found in Roswell and North Spring River Valley, the extreme north end of the basin.

In amount of flow the wells vary from a few gallons to 1,800 gallons a minute, differing principally with the locality. At Roswell the flow of an average well has been variously estimated at 500 to 700 gallons, while near Artesia the highest flow recorded exceeds 1,700 gallons. The water is used chiefly for irrigation and domestic purposes. In a few cases, however, the presence of sulphur renders it unfit for household use. The Formwaltz well northeast of Hagerman is said to have medicinal properties, but no chemical analysis of the water was obtained.

As the conditions under which artesian water is obtained throughout the Roswell basin show considerable variation, the area in the following discussion is divided into four districts—Roswell, Hagerman, Artesia, and McMillan. The Roswell and Hagerman districts are in Chaves County, and the Artesia and McMillan districts are in Eddy County.

CHAVES COUNTY.

Roswell district.—This district comprises the northern portion of the area of flow included in Chaves County, and, as stated above, it is the district where greatest development has taken place. In Roswell and in Hondo Valley the depths of the wells vary from 150 to 500 feet, the average being 250 feet. To the southeast in the vicinity of Orchard Park flows are



MAP OF THE ROSWELL ARTESIAN BASIN SOUTHEASTERN NEW MEXICO

BY C.A.FISHER

Topography compiled from railroad data and barometer readings

Scale

2 0 2 4 6 8 10 miles

Contour interval 100 feet

1905

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obtained at a much greater depth. The formations encountered in sinking a well at Roswell generally consist of unconsolidated deposits for the first 175 feet from the surface. Below this depth drills penetrate bed rock, composed of hard, light-colored limestone underlain by alternating layers of porous limestone and sandstone. The following are records of representative wells in and near Roswell:

Typical well records in and near Roswell, N. Mex.

	Feet.
Record of the Ogle well at Roswell:	
Soil	0– 5
Gravel	5– 30
Blueish clay with layers of gravel	30–150
Greenish-yellow clay with rust-colored bands	150–162
Soft red sandstone (water bearing)	162–170
Red clay	170–174
Gray limestone	174–177
Red clay	177–178
Gray limestone	178–182
Gray limestone, very hard	182–186
Soft gray limestone	186–204
Hard gray limestone	204–218
Light-gray, porous limestone (water bearing)	218–226
Limestone and sandstone in alternate layers (water bearing)	226–242
Record of the Waskom well, SW. ¼ sec. 32, T. 10 S., R. 25 E.:[a]	
Soil	0– 5
Sand and gravel	5– 15
Yellow clay	15– 40
Clay and decomposed gypsum	40– 70
Sandstone, coarse yellow sand, and gravel in alternate succession	70–360
Limestone and sandstone in alternating layers, the limestones predominating	360–560
Record of the Rasmussen well, SW. ¼ sec. 21, T. 11 S., R. 25 E.:	
Soil and fine sand	0– 30
Gray sand	30– 40
Gravel	40– 50
Rock and gravel in alternate layers	50– 60
Red sand	60– 65
Gray sand and hard rock in thin layers	65–172
Quicksand	172–212
Red sandstone	212–327
Red sand containing layers of rock	327–400
Limestone	400–560

Partial list of artesian wells in Roswell district, New Mexico.

Name of owner and location.	Depth.	Diameter.	Yield[b]
Anderson:	*Feet.*	*Inches.*	*Galls. per minute.*
SE. ¼ sec. 3, T. 11 S., R. 25 E	60	6	....
Do	60	6	....
Do	58	6	....
Anderson & Skillman, lot 7, block 16, West Roswell	440	4	400
"Bottomless Lake" well, SE. ¼ NW. ¼ sec. 10, T. 12 S., R. 26 E	420	6	....
Bradley & Beal, lot 6, block 53, West Roswell	232	5⅝	600
Brink, Fritz, lot 14, block 23, west side Roswell	235	5⅝	500
Brown & Creighton, lot 11, block 4, original Roswell	238	5⅜	500
Cahoon, E. A.:			
NW. ¼ NW. ¼ sec. 34, T. 10 S., R. 24 E	340	4½	402
Lot 6, block 21, west side Roswell	229	4	250
Chambers, R. M., lot 4, block 24, original Roswell	244	4⅝	600
Champion, D., NW. ¼ NW. ¼ sec. 27, T. 10 S., R. 24 E	330	7⅝	300

[a] In this well, located 4 miles east of Roswell, bed rock was reached at a depth of 360 feet.
[b] Mainly estimated.

Partial list of artesian wells in Roswell district, New Mexico—Continued.

Name of owner and location.	Depth.	Diameter.	Yield.[a]
	Feet.	*Inches.*	*Galls. per minute.*
Chaves Co., block 11, Roswell	206	5⅝	675
Church, J. P., lot 8, block 45, West Roswell	270	5⅝	500
Cottingham, J. A., lot 13, block 19, original Roswell	202	5⅝	600
Davis, W. P., SE. ¼ NE. ¼ sec. 7, T. 11 S., R. 25 E	450	5⅝	500
Denning, S. P., lot 8, block 51, west side Roswell	240	5⅝	580
Diamond ice factory, lot 1, block 7, Thurber's addition, Roswell	196	5⅝	700
Dickson, J., northwest corner Washington and 2d sts., Roswell	270	5⅝	660
Dickson, J. M., lot 5, block 52, west side Roswell	198	5⅝	400
Divers, F., lot 2, block 9, west side Roswell	232	5⅝	600
Dunn, G., T. 12 S., R. 26 E	264	6⅝	410
Evans, J. F., lot 8, block 28, original Roswell	200	4	250
Elliott Bros., SW. ¼ SW. ¼ sec. 32, T. 12 S., R. 25 E	859	6	612
Faulkner, R. L., lot 10, block 12, west side Roswell	198	5	500
Ferguson, W. M.:			
Lot 10, block 2, original Roswell	255	4½	320
NE ¼ NW. ¼ sec. 15, T. 12 S., R. 25 E	882	6⅝	987
Finley, M. N., SW. ¼ SW. ¼ sec. 3, T. 11 S., R. 24 E	354	7⅝	150
Fitzgerald & Kingston, lot 1, block 17, original Roswell	200	5⅝	600
Fitzgerald, lot 12, block 26, original Roswell	190	5⅝	500
Frank, C. J., lot 9, block 10, original Roswell	202	5⅝	600
Garrett, A. D., lot 1, block 20, west side Roswell	260	5⅝	500
Garst, J., lot 2, block 1, original Roswell	271	3	250
Garst, Julius, SE. ¼ SW. ¼ sec. 28, T. 10 S., R. 24 E	279	6⅝	....
Gaslin, H., lot 10, block 48, west Roswell	242	4½	350
Gaullier, lot 6, block 1, original Roswell	265	5⅝	680
Goodart, J. H., NW. ¼ NE. ¼ sec. 7, T. 11 S., R. 25 E	400	4⅝	600
Hagerman, O., lot 3, block 24, South Roswell	405	5	680
Hamilton, R. S., lot 12, block 14, original Roswell	301	5⅝	800
Hamilton, J., SW. ¼ SW. ¼ sec. 26, T. 10 S., R. 24 E	313	6⅝	400
Haynes, C. W.:			
Lot 7, block 20, South Roswell	310	5⅝	750
Roswell	232	5⅝	750
Do	204	7⅝	750
Do	232	5⅝	700
Henning, J. H., lot 7, block 11, west side Roswell	235	5	400
Hinkle, J., lot 7, block 51, west side Roswell	235	4½	400
Hobson, Lowe & Co., lot 9, block 3, original Roswell	270	5⅝	600
Hortenstein, NW. ¼ SW. ¼ sec. 23, T. 12 S., R. 25 E	840	5⅝	349
Jaffa, N., lot 10, block 3, Thurber's addition, Roswell	200	3	200
Jaffa & Prager, lot 13, block 14, Roswell	380	4	450
Johnson, R. W., lot 7, block 24, west side Roswell	250	5⅝	750
Lawndes, G., NW. ¼ NW. ¼ sec. 35, T. 11 S., R. 25 E	287	....	300
Lea, J. C., lot 5, block 4, original Roswell	230	6⅝	750
L. F. D. stock farm, SE. ¼ NW. ¼ sec. 1, T. 11 S., R. 24 E	383	6⅝	596
	333	4½	100
McCarty, S. S., N. ½ NW. ¼ sec. 14, T. 10 S., R. 25 E	844	5⅝	300
McClenney, M. E., SE. ¼ SE. ¼ sec. 35, T. 10 S., R. 24 E	375	7⅝	600
Marrow & Tannehill, lot 14, block 13, old Roswell	260	5	500
Meeks, W., lot 6, block 28, original Roswell	160	4	250
Miller, J., lot 4, block 30, original Roswell	230	5⅝	580
New Mexico Military Institute, Roswell	232	6⅝	....
Parsons, R. M., lot 5, block 54, west side Roswell	245	5⅝	675
Patterson, J. F., lot 1, block 42, west side Roswell	260	3	250

[a] Mainly estimated.

Partial list of artesian wells in Roswell district, New Mexico—Continued.

Name of owner and location.	Depth.	Diameter.	Yield.[a]
	Feet.	*Inches.*	*Galls. per minute.*
Peck, J. C., NE. ¼ SW. ¼ sec. 27, T. 10 S., R. 24 E	333	5⅝	400
Pecos Valley and Northeastern Railroad, Roswell (pressure 12 pounds)	248	5⅝	820
Pettey & Miller, lot 6, block 14, original Roswell	225	6⅝	750
Pierce, F., lot 3, block 10, west side Roswell	264	5⅝	600
Rasmussen, E. P., SW. ¼ sec. 21, T. 11 S., R. 25 E	560	5⅝	....
Ray, J. R., lot 6, block 21, west side Roswell	221	5⅝	600
Read, G. W., lot 9, block 6, original Roswell	224	4	400
Redderson, G., lot 11, block 18, west side Roswell	250	5⅝	600
Ried, C. M., lot 3, block 12, west side Roswell	175	4½	300
Roach T., lot 10, block 21, west side Roswell	250	5⅝	600
Roach, T. S., lot 9, block 21, west side Roswell	240	5⅝	500
Rogers, A. C., sec. 25, T. 10 S., R. 24 E	142	3⅝	2
Rose, I. B., lot 7, block 40, west side Roswell	241	5⅝	600
Ross, F., lot 2, block 3, original Roswell	245	5⅝	500
Roswell Wood and Hide Co., lot 7, block 18, original Roswell	262	4½	660
Roswell (town):			
Block 23, west side	163	5⅝	500
Block 41, west side	260	5⅝	600
Block 47, west side	270	5⅝	600
Seay, E.:			
Lot 8, block 38, west side Roswell	205	5⅝	500
Lot 11, block 38, West Roswell	170	4½	400
Sheridan, C., lot 7, block 7, original Roswell	250	5⅝	580
Skipwith, J. H., lot 12, block 8, original Roswell	249	5	500
Slakey, H. B., lot 9, block 57, west side Roswell	218	5⅝	500
Slaughter, C. C., sec. 34, T. 10 S., R. 24 E., Center	275	5⅝	550
Slaughter, G., Thurber's addition, Roswell	225	5⅝	460
Smith, L. R., SW. ¼ NW. ¼ sec. 27, T. 10 S., R. 24 E	330	7⅝	300
Smock, W. S., lot 4, block 50, west side Roswell	235	5⅝	600
Spurlock, SW. ¼ sec. 31, T. 11, S., R. 24 E	917	6⅝	324
Stansell, C. N., NE. ¼ SW. ¼ sec. 11, T. 11 S., R. 24 E	340	7⅝	350
Stevens, L. A., lot 11, block 19, original Roswell	220	5⅝	360
Sutherland, lot 5, block 27, original Roswell	300	5⅝	660
Tipton, W., lot 19, block 6, South Roswell	300	5⅝	....
Totsek, S., lot 6, block 42, west side Roswell	238	5⅝	600
Veal, G. F., lot 10, block 5, original Roswell	361	5⅝	600
Waldron, C. E., lot 11, block 22, west side Roswell	240	5⅝	600
Wallace, J. A., lot 5, block 39, west side Roswell	155	5	200
Warren, J. R., lot 1, block 23, west side Roswell	150	4	200
Waskom, A. B., SW. ¼ sec. 32, T. 10 S., R. 25 E	560	6⅝	756
Wells, W. F., lot 1, block 1, Roswell	230	5⅝	660
Whiteman, C., lot 1, block 6, Thurber's addition, Roswell	170	5⅝	400
Wilkenson, W. G., lot 6, block 57, west side Roswell	234	5⅝	580
Wilson, B., lot 8, block 44, west side Roswell	235	5⅝	600
Woodruff & Hedgecoxe, lot 13, block 15, original Roswell	205	5⅝	660
Wyllys, G. L., lot 7, block 58, West Roswell	249	5⅝	780
Yater, B. M., lot 7, block 26, original Roswell (pressure about 7 pounds)	203	5¾	750

[a] Mainly estimated.

Hagerman district.—In the immediate vicinity of Hagerman there are a few flowing wells, but about 8 miles north, near Dexter and in the lowlands east of Pecos River, there are several. They vary in depth from 300 to 1,000 feet, and the beds penetrated differ somewhat from those of the Roswell district. In the lowlands of Pecos Valley flows of moderate

yield are obtained in soft sandstones at depths of 300 to 500 feet, but on the higher slopes to the west the main flow occurs in porous limestones 800 to 1,000 feet below the surface. The Hedgecoxe well, about 1 mile southeast of Dexter, is 960 feet deep. The main flow occurs in a porous limestone underlying red sandstone 60 feet thick, which is overlain by unconsolidated material.

The following records of wells were furnished by the drillers:

Typical deep borings in Hagerman district, New Mexico.

	Feet.
Record of the Hedgecoxe well, near Dexter:	
Soil and gravel	0- 19
Coarse sand	19- 71
Quicksand	71- 271
Limestone	271- 273
Red sandy clay	273- 323
Yellow clay	323- 343
Limestone	343- 345
Quicksand	345- 545
Limestone	545- 551
Blue clay	551- 601
Quicksand	601- 651
"Shell rock"	651- 653
Alternating layers of sand, silt, and clay	653- 800
Coarse gravel	800- 806
Red sandstone	806- 866
Porous limestone	866- 960
Record of Widdeman well:	
Soil	0- 20
Gravel	20- 55
Quicksand	55- 105
Alternating beds of clay and gypsum	105- 360
Sand	360- 440
Red sand with layers of clay and one 25-foot layer of gypsum near the middle	440- 800
Limestone	800-1,000
Record of Cummins well:	
Soil and gravel	0- 40
Sand	40- 44
Clay	44- 60
Gravel	60- 65
Rock, clay, and sand in alternate layers	65- 105
Clay and sand	105- 165
Red sand	165- 550
Coarse red sand and clay in alternate layers	550- 820
Limestone	820- 840
Partial record of town well at Hagerman:[a]	
Soil	1- 12
Conglomerate	12- 22
Sand	22- 32
Clay	32- 60
Alternating beds of coarse sand and gravel	60- 535
Gypsum and red sandy clay in alternate beds	535- 610
Gypsum	610- 630
Red clay and sand	630- 675
Hard gypsum	675- 732
Hard, gray sandstone	732- 735
Gypsum	735- 745
Red clay and sand	745- 750
Gypsum	750- 760

[a] Boring in progress at time investigation was made.

A. RASMUSSEN'S WELL, EAST OF SOUTH SPRING, NEW MEXICO.

B. WIDDEMAN'S WELL, NEAR DEXTER, N. MEX.

Partial record of H. H. Sigman's well near Lake Arthur:[a]

	Feet.
Soil and conglomerate	0– 5
Hard gypsum (first flow at base)	5– 130
Alternating strata of gypsum and red sand	130– 235
Alternating layers of red sand and clay	235– 345
White sand	345– 545
Red sand	545– 600

Partial list of artesian wells in Hagerman district.

Name of owner and location.	Depth.	Diameter.	Yield.[1]
	Feet.	*Inches.*	*Gallons (per minute).*
Calloway, E. H., T. 13 S., R. 26 E	454	....	20
Carper, J. E., NW. ¼ NE. ¼ sec. 28, T. 12 S., R. 26 E	330	8	377
Casiers, T. M., NE. ¼ NW. ¼ sec. 7, T. 13 S., R. 26 E	400	$6\frac{5}{8}$	351
Clem, J. A., E. ½ sec. 11, T. 13 S., R. 26 E	525	$7\frac{5}{8}$	517
Criser, F. A., E. ½ NW. ¼ sec. 33, T. 12 S., R. 26 E	500	$5\frac{5}{8}$	300
Cummins, J. Q., SE. ¼ sec. 33, T. 12 S., R. 25 E	860	$6\frac{5}{8}$	250
Elliot, I. H	760	$4\frac{1}{2}$	....
Formwault, SW. ¼ sec. 31, T. 12 S., R. 26 E	960	$6\frac{5}{8}$	848
Forstad, J., NE. ¼ sec. 13, T. 13 S., R. 26 E	664	$7\frac{5}{8}$	25
Geyer	300	$5\frac{1}{2}$	....
Goodell, S. W., S. ½ sec. 15, T. 13 S., R. 25 E	839	8	....
Greenfield farm (center), sec. 32, T. 13 S., R. 26 E	....	$5\frac{5}{8}$	....
Hagerman (town), NE. ¼ SE. ¼ sec. 10, T. 14 S., R. 26 E	760	8	....
Hedgecoxe, NE. ¼ NE. ¼ sec. 18, T. 13 S., R. 26 E	960	$6\frac{5}{8}$	600
Lake Arthur, sec. 20, T. 15 S., R. 26 E	1,000	10	764
Large, Frank:			
Sec. 4, T. 13 S., R. 26 E	375	$5\frac{5}{8}$	420
Sec. 4, T. 13 S., R. 26 E	460	$7\frac{5}{8}$	599
Sec. 4, T. 13 S., R. 26 E	460	$7\frac{5}{8}$	599
Townsley, H. W.:			
NW. ¼ sec. 4, T. 13 S., R. 26 E	440	$5\frac{5}{8}$	....
NW. ¼ sec. 4, T. 13 S., R. 26 E	450	$5\frac{5}{8}$	....
Walters, L., SE. ¼ sec. 14, T. 13 S., R. 26 E	505	$5\frac{5}{8}$	310
Widdeman, NW. ¼ sec. 5, T. 13 S., R. 26 E	1,000	....	....
Wilson, P., NW. ¼ sec. 18, T. 13 S., R. 27 E	620	....	20
Winchell, N. J., SE. ¼ SW. ¼ sec. 30, T. 13 S., R. 26 E	1,025	8	880

[1] Mainly estimated.

EDDY COUNTY.

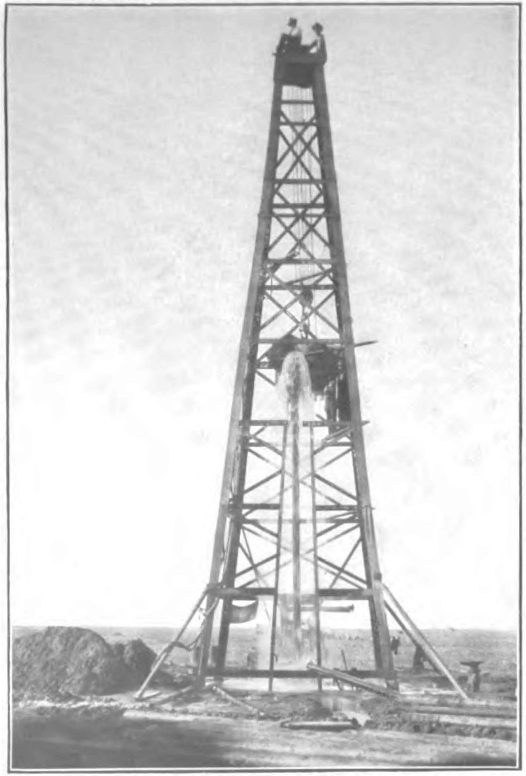
Artesia district.—The Artesia district comprises the northern portion of the area of flow included in Eddy County. The formations encountered in boring a deep well near Artesia differ somewhat from those in other parts of the Roswell basin. According to well records they consist for the first 500 to 700 feet of unconsolidated beds of sand, gravel, and clay, which by their loose texture frequently offer considerable difficulty in well construction. Beneath these beds there are alternating layers of red and gray sandstone, clay, and gypsum lying on a series of porous limestones, clays, and sandstones, in which the strongest artesian flows occur. A number of records of deep borings around Artesia, as reported by the well drillers, are here given:

[a] No satisfactory record, particularly of the lower part, could be obtained of this boring, which was originally 1,000 feet deep. There is probably some defect in the casing of the well, for, according to the latest reports, the lower part of the pipe appears to be clogging up with sediment, and there is a perceptible decrease in the pressure of the flow. The best information which could be obtained concerning the formations penetrated in the upper part of this well is here given.

Typical deep borings in Artesia district, New Mexico.

	Feet.
Record of the J. C. Hale well, 1¼ miles southeast of Artesia:	
Soil	0- 10
Red clay	10- 30
White, coarse sand	30-100
Fine sand	100-120
Bluish clay alternating with sandy layers	120-375
Red clay with layers of gravel	375-540
White sand	540-550
Yellow sand	550-556
Red, sandy clay	556-581
Limestone	581-585
Red, sandy clay alternating with layers of gravel	585-745
Gravel	745-751
Hard limestone	751-760
Limestone and red clay	760-794
Hard and soft light-colored limestone with layers of sandstone	794-820
Soft, red sandstone	820-830
Hard, porous limestone and red clay in alternate succession, the limestone predominating	830-850
Record of the J. S. Majors artesian well, 2 miles north of Artesia:	
Loamy soil	0- 6
Bowlders	6- 15
Concretionary conglomerate	15- 40
Rock	40- 62
Soft sands	62- 68
Rocks and bowlders	68- 70
Gray sand	70- 72
Soft clay	72-160
Moderately hard rock	160-174
Red, sticky clay	174-210
Sticky clay and gravel	210-240
Coarse, white sand	240-275
Clay and gravel	275-290
Soft rock	290-295
Clay	295-310
Red quicksand	310-320
Red clay	320-357
Soft rock	357-360
Soft clay (First flow yielding about 10 gallons per minute)	360-420
Hard rock	420-428
Clay and gravel; some sand	428-460
Clay and sand	460-542
Soft rock and clay	542-560
Tough, red clay	560-598
Hard rock	598-600
Hard clay	600-617
Hard rock	617-628
Red clay	628-630
Soft rock	630-634
Hard rock	634-640
Sand and clay	640-665
Soft rock, clay, and sand	665-700
Quicksand	700-704
Hard rock (limestone; second flow at base)	704-714
Alternating strata of soft rock and clay	714-770
Soft and hard rock in alternate layers	770-795
Very hard rock (limestone)	795-798
Clay and soft rock	798-812
Extremely hard rock (limestone)	812-820
Rock, increasing in hardness	820-823
Record of the Hodges & Venable artesian well, Artesia:[a]	
Soil	0- 10
Bowlders and clay	10- 19
Concrete rock	19- 26

[a] In this well flows were obtained at the following depths: First flow, 450 feet; second flow, 648 feet, third flow, 785 feet; fourth flow, 802 feet.



A. ARTESIAN TOWN WELL, AT ARTESIA, N. MEX.

B. SHERMAN'S PUMPING PLANT, NEAR ROSWELL, N. MEX.

Record of the Hodges & Venable artesian well, Artesia—Continued.	Feet.
Loose gravel	26 - 41
Concrete rock	41 - 46
Red clay	46 - 73
Concretionary gravel	73 - 76
Loose gravel	76 - 86
Hard limestone	86 -113
Loose gravel containing water	113 -120
Limestone	120 -130
Red clay	130 -155
Red clay alternating with conglomerate	155 -185
Alternating strata of concretionary conglomerate and red clay	185 -250
Red clay	250 -350
Alternating layers of red, sandy clay and sandstone	350 -545
Limestone, with an occasional layer of red clay, very hard at base of series	545 -840
Record of the J. B. Barnes artesian well, 12 miles southwest of Artesia:	
Soil	0 - 6
Bowlders and gravel	6 - 13
Yellow clay and gravel	13 - 53
Red clay	53 -153
Quicksand	153 -157
Red sand and soft sandstone	157 -177
Soft, yellowish sandstone	177 -227
Hard limestone	227 -267
Red, sandy clay alternating with soft red sandstone, which gives place to porous limestone in the lower half of the series. (First flow)	267 -450
Soft, red sandstone	450 -500
Porous limestone	500 -525
Soft, red sandstone	525 -535
Record of the S. L. Roberts artesian well, at Artesia:	
Soil	0 - 7
Bowlders and gravel	7 - 42
Red, sandy clay containing some gravel	42 -200
Quicksand	200 -260
Red clay	260 -300
Alternating layers of gray sand and red clay	300 -600
Limestone	600 -604
Gypsum	604 -634
Red clay	634 -675
Limestone	675 -679
Red clay	679 -704
Limestone	704 -705½
Red, sandy clay	705½-745½
Limestone	745½-840
Hard limestone	840 -852
Red, sandy clay	852 -880
Limestone, porous	880 -976
Record of the E. N. Heath artesian well, 2 miles southwest of Artesia:	
Soil and clay	0 - 15
Gravel	15 - 30
Yellow clay	30 - 80
Gravel and sand	80 -280
Sand	280 -310
Gravel and sand	310 -340
Hard, red clay	340 -344
Gypsum	344 -346
Conglomerate	346 -366
Sand with thin streaks of gravel	366 -441
Coarse-grained, porous rock	441 -461
Gray sand	461 -481
Red quicksand	481 -631
Rock	631 -641
Red quicksand	641 -691
Hard, gray limestone	691 -715
Red sand rock with streaks of clay	715 -725
Gray limestone, very hard	725 -745

Record of the W. E. Clark artesian well, 4 miles north of Artesia:

	Feet.
Soil	0- 6
Bowlders and gravel	6- 16
Gypsum	16- 76
Gravel	76- 81
Gypsum	81- 90
Concretionary conglomerate	90- 95
Hard gray sandstone	95-106
Red clay streaked with white clay	106-126
Dark-gray sandstone	126-157
Yellow sand	157-200
Hard gray sandstone	200-218
Red sand	218-232
Very hard light-gray sandstone	232-244
Red sand	244-247
Hard red rock	247-250
Red sand	250-268
Hard red rock	268-274
Alternating strata of quicksand and soft red sandstone	274-536
(In this series at 385 feet occurs the first flow; second flow at 475 feet.)	
Very hard limestone	536-540
Red sandstone, medium hardness	540-580

The greatest development in well sinking in this district is around Artesia, where a number of strong artesian flows have been obtained at depths of 800 to 1,000 feet. A partial list of these wells, including their location, depth, and size, is given in the following table:

Partial list of artesian wells in Artesia district.

Name of owner and location.	Depth.	Diameter.	Yield.[a]
	Feet.	*Inches.*	*Galls. per minute.*
Artesia (town), NE. ¼ NE. ¼ sec. 17, T. 17 S., R. 26 E.[b]	771	6	....
Barnes, J. B., NW. ¼ NW. ¼ sec. 23, T. 18 S., R. 25 E	535	6	1,548
Bruce, J. A., NE. ¼ NE. ¼ sec. 14, T. 17 S., R. 26 E	872	5⅝	562
C. A. P. Cattle Co., SW. ¼ NE. ¼ sec. 23, T. 17 S., R. 26 E	830	....	....
Clark, W. E.[c]	580	....	....
Deiss, J. J., sec. 32, T. 18 S., R. 26 E	570	6	....
Gilberts, S. W., SW. ¼ sec. 7, T. 18 S., R. 26 E	813	6	320
Gilliland, J. W., SE. ¼ sec. 9, T. 18 S., R. 26 E.[d]	826	6	....
Hale, J. C., NW. ¼ SE. ¼ sec. 15, T. 17 S., R. 26 E	850	6	1,168
Harris, N. T., SW. ¼ SW. ¼ sec. 14, T. 16 S., R. 26 E.[c]	....	....	....
Heath, E. N., SE. ¼ sec. 18, T. 17 S., R. 26 E	746	6⅝	....
Hodges & Venable, SE. ¼ NW. ¼ sec. 23, T. 18 S., R. 25 E	840	6	1,110
Majors, J. S., SW. ¼ SW. ¼ sec. 31, T. 17 S., R. 26 E	823	....	....
Miller, L. C., SW. ¼ SW. ¼ sec. 8, T. 18 S., R. 26 E	671	6	1,044
Norfleet, A. L., S. ½ NW. ¼ sec. 32, T. 17 S., R. 26 E	....	....	....
Rawl & Robertson, sec. 5, T. 17 S., R. 26 E	650	....	....
Richey, John, SW. ¼ SW. ¼ sec. 11, T. 16 S., R. 26 E.[b]	835	....	....
Roberts, S. L., SE. ¼ SW. ¼ sec. 8, T. 17 S., R. 26 E	976	....	....
Smith, J. Mack, SW. ¼ NW. ¼ sec. 29, T. 17 S., R. 26 E	747	6⅝	1,725
Smith & Beckman, sec. 17, T. 17 S., R. 26 E	881	....	....
Stanford, L. G., NE. ¼ sec. 34, T. 18 S., R. 26 E	797	6	....
Walterschied, W. M., E. ½ SW. ¼ sec. 8, T. 17 S., R. 26 E	795	6	....

[a] Mainly estimated. [b] 92½ pounds pressure. [c] Incomplete. [d] 72½ pounds pressure.

McMillan district.—This district includes the area in the vicinity of McMillan and the valleys of North and South forks of Seven Rivers. Near McMillan the Walters & Shavers and the Lakewood Townsite companies' wells have strong flows from the porous limestone at depths of about 800 feet. The records of these wells indicate that the unconsolidated

sediments are about 250 feet thick and that the limestone division occurs 500 to 600 feet below the surface. The records of these wells were supplied by the drillers as follows:

Typical deep borings in McMillan district, New Mexico.

Record of the Walters & Shavers artesian well at McMillan:	Feet.
Soil	0- 6
Coarse gravel	6- 13
White clay	13- 33
Coarse sand and gravel containing water	33- 43
White chalky rock	43- 70
Very hard gray sandstone with layers of gravel	70-170
Hard flinty rock	170-177
Red clay and coarse gravel in alternate succession	177-235
Light-colored sandy clay	235-250
Red clay	250-254
Alternating strata of gypsum and red clay	254-370
Hard gypsum	370-393
Series of gypsum alternating with red clay	393-440
Alternating layers of white gypsum and red sandstone	440-500
Red sand and hard sandstone in alternate layers 2 feet thick	500-650
Hard white limestone	650-800
Extra hard limestone	800-820
White limestone becoming softer. (Flow of about 300 gallons)	820-845
Record of the Lakewood Townsite Company artesian well at McMillan:	
Loam and gravel	0- 49
Soft gypsum in strata 5 to 6 feet thick	49- 80
White chalky rock	80-120
Sandstone and gypsum in alternating layers	120-135
Pure white gypsum, moderately hard	135-200
Very hard white gypsum	200-450
Soft rock resembling shale	450-490
Alternating layers of hard and soft white rock containing a few thin layers of sandstone. (First flow at 770 feet, second flow at 810 feet)	490-863
Very soft, white rock	863-877
Alternating layers of soft and hard limestone	877-880

In Seven Rivers Valley wells are generally shallow, ranging in depth from 150 to 300 feet, and the flows so far have been obtained from the unconsolidated rock. It is probable, however, that wells sunk to a sufficient depth in this region would obtain flows from the limestone division. A partial list of the wells in the McMillan district is given in the following table, and their location is shown on Pl. VI:

Partial list of artesian wells in McMillan district.

Name of owner and location.	Depth.	Diameter.	Yield.
	Feet.	*Inches.*	*Galls. per minute.*
Brogden, J. C.:			
SE. ¼ SE. ¼ sec. 15, T. 20 S., R. 25 E	305	5⅝	573
Sec. 21, T. 20 S., R. 25 E	150?	5⅝	253
Boyd, G. M., SE. ¼ sec. 26, T. 19 S., R. 25 E	549	5⅝	....
Cole, SE. ¼ sec. 7, T. 20 S., R. 25 E	195	6	....
Eatons	400	....	....
Hellyer, W. E	190	6	12
Lakewood Townsite Co., sec. 27, T. 19 S., R. 26 E	885	6	....
McDonald:			
NW. ¼ sec. 8, T. 20 S., R. 25 E	146	5⅝	75
NW. ¼ sec. 8, T. 20 S., R. 25 E	150	5⅝	....
Plott, J. C., S. ½ NE. ¼ sec. 26, T. 19 S., R. 25 E	347	5⅝	....
Walters & Shavers, NW. ¼ NW. ¼ sec. 23, T. 19 S., R. 26 E	845	6	300

PRESSURE OF ARTESIAN WATER.

In connection with the investigation of the geology and underground water relations of the Roswell basin a systematic measurement of well pressures has been carried on. At the time when this investigation was proposed there appeared to be no evidence that the flow was decreasing, but it was feared that the multiplicity of wells within such a limited area would eventually lower the water plane unless greater economy was practiced by the water users. In arranging for the testing and comparison of pressures a number of representative wells were selected at different points throughout the basin, four from Roswell, where many have been sunk in a relatively small area, and others from near Hagerman and Artesia. In making these selections care was exercised to obtain only those which were believed to be representatives of local districts and in perfect condition. In a few instances, however, defective pipes were discovered after the first monthly pressure had been recorded. Careful measurements were taken of these wells each month under uniform conditions so far as possible. The result of this investigation extending over a period of twelve months is shown in the following table:

Record of periodic pressure measurements in pounds per square inch, of artesian wells in the Roswell artesian basin, New Mexico, for year ending May 31, 1905. [a]

No.	Name and location.	June.	July.	August.	September.	October.	November.	January.	February.	March.	April.	May.	Total loss or gain.
	ARTESIA DISTRICT.												
1	Gilliland, [b] SW. cor. SE. ¼ sec. 19, T. 18 S., R. 26 E.	83	82	80	79	80	79	74	74	72½	69	69	−14
2	Hale, [c] NW. ¼ SE. ¼ sec. 15, T. 17 S., R. 26 E.	88	87	87	84	84	82	80	81	77½	77½	77½	−10½
3	Hodges & Venable, [b] middle of west line SE. ¼ NW. ¼ sec. 23, T. 18 S., R. 25 E.	31½	31½	30½	30	29	27	25	25½	24	21	21	−10½
4	Norfleet, [b] NW. cor. of S. ½ NW. ¼ sec. 32, T. 17 S., R. 26 E.	....	....	62½	61	61	58	55	56	54½	53	53	− 9½
5	Richey, [b] SW. ¼ NE. ¼ sec. 14, T. 16 S., R. 26 E.	....	....	....	....	....	95½	92	94	92½	91	91	− 4½
	HAGERMAN DISTRICT.												
6	Greenfield farm, [d] sec. 32 (center), T. 13 S., R. 26 E.	58	58	57	57	55	53½	53	53	54	....	....	......
7	Sigman, H. H., [b] NW. ¼ sec. 20, T. 15 S., R. 26 E.	....	....	....	....	....	41	33	30½	....	25	27	−14
8	Widdeman, A. J., [b] SW. ¼ SW. ¼ sec. 5, T. 13 S., R. 26 E.	....	40	40	40	38	41	41½	39½	39	39	39	− 1
	ROSWELL DISTRICT.												
9	Hagerman, J. J., [b] near center of west line NW. ¼ SE. ¼ sec. 13, T. 11 S., R. 24 E.	13	13	13	13½	13⅓	13⅓	13⅓	13⅓	14	13⅓	13½	+ ½
10	Hamilton, [b] lot 12, block 14 (original townsite), SW. ¼ SW. ¼ sec. 33, T. 10 S., R. 24 E.	6⅔	6⅔	7⅔	7	7	7⅔	7	7⅔	8	8	8	+ 1⅓
11	McClenny, [e] SE. ¼ SE. ¼ sec. 35, T. 10 S., R. 24 E.	16⅔	16⅔	20	20	20	21	20	21½	22	21½	21½	+ 4⅚
12	Parsons, [b] lot 4, block 54 (west side), NE. ¼ SE. ¼ sec. 32, T. 10 S., R. 24 E.	7	7	7	7	7	7	7	7½	8	8	8	+ 1
13	P. V. and N. E. roundhouse, [f] NE. cor. NW. ¼ SW. ¼ sec. 33, T. 10 S., R. 24 E.	12	10	10	12	12	12	12	13	13	13	13	+ 1
14	Rasmussen, [b] SW. ¼ NW. ¼ sec. 21, T. 11 S. 25 E.	31	31	31	31	31	32½	33	31	31½	31½	31½	+ ½
15	Yater, [b] lot 7, block 26 (original townsite), NE. ¼ SE. ¼ sec. 32, T. 10 S., R. 24 E.	7	7	7	7	7	7	7	7	10	....	10	+ 3

[a] No measurements were obtained for December.
[b] Casings of Nos. 1, 4, 5, 7, 9, 10, 12, 14, and 15 were in perfect condition, or apparently so; slight leakage at valve of Nos. 1, 3, and 8.
[c] Decrease in pressure may be due to escape of water into a higher artesian horizon, which is reached by a shallow well not far away.
[d] This is an old well and the casing may be defective.
[e] Low pressures in the months of June and July due to leakage in pipe.
[f] Slight leakage in casing near surface and at valve caused a decrease of pressure in July and August measurements.

In most cases in the Roswell and Hagerman districts, where the wells were in perfect condition, the pressures of the flows appear to be substantially accordant, but around Artesia there are several wells in which the flows have materially decreased in pressure during the last twelve months. Without a thorough knowledge of the conditions under which artesian water is obtained around Artesia the decrease in pressure of some of the strongest flows in that vicinity might at first appear alarming, but a comparison of this district with that of Roswell, where there is no decrease in pressure, introduces many important factors which have a direct bearing on the case.

At Roswell artesian water is obtained at a depth of about 250 feet, and the materials passed through offer practically no difficulty; as a result, very perfect wells are constructed. Then, too, in this region wells have been built for the last decade, and the well driller is so familiar with the conditions that he can predict with a fair degree of accuracy the materials to be encountered in sinking a well. Farther south in the basin, in the vicinity of Artesia, a successful artesian well is not so easily obtained. Here the main flow is reached at much greater depths, which range from 700 to 900 feet, depending on the location. The increased depth is due to the presence of beds overlying the porous limestone series. They consist of red sand and gypsum of the supposed Permian series, and clay, fine sand, and gravel of the unconsolidated deposits. The sands predominate throughout and have often a loose texture familiarly known to the well driller as quicksand. This material is very difficult to drill through because of caving, and in one or two instances it was so troublesome that the owner was compelled to abandon the project. The pressure at the surface in an average well around Artesia is about 80 pounds to the square inch, which means over 400 pounds to the square inch at the bottom of a well 800 feet deep. Such forces are difficult to manage, particularly where exploitation in the region has not been sufficiently extensive to enable the well driller to thoroughly acquaint himself with the nature of the obstacles to be encountered, and make suitable provision for them. The region is also one that offers considerable inducement to the ambitious well driller. As a result, new machines are constantly coming into this field, and the operators, though skilled in the art of well drilling, are entirely unfamiliar with this locality. It can readily be seen that under these circumstances imperfect wells are likely to result. Some of the strongest flows in the basin are and have been unmanageable since their completion, while others owing to unfavorable conditions are not working satisfactorily.

COMPOSITION OF ARTESIAN WATERS.

General statements.—The artesian waters of the Roswell basin are all more or less mineralized, but in only a few cases are the mineral constituents present in sufficient amounts to materially affect the taste or to be deleterious to plant growth. An average sample of the waters of North and South Spring rivers contains 75 parts of soluble matter to 100,000 parts of water. About two-thirds of the total solids consists of calcium carbonate and calcium sulphate, which are regarded as harmless to plants. The more soluble ingredients of the water, consisting of sodium chloride, magnesium sulphate, and potassium sulphate, occur in amounts too small to injure plant growth if the ground is properly

drained. The following analyses of waters of North and South Spring rivers were made by Prof. E. M. Skeats, of El Paso, Tex.:

Analyses of water from springs in North Spring and South Spring rivers.

SAMPLES FROM MARGINAL SPRINGS IN NORTH SPRING RIVER.

[Parts per million.]

	Total solids.	Silica (SiO_2).	Water.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Chlorine (Cl).	Sulphuric acid (SO_4).	Carbonic acid (CO_3).
No. 1	820	15	84.7	122.3	46.8	57.5	93.6	281.9	118.1
No. 2*	710	20	96.9	146.6	48.8	8.5	56.4	240.6	116.9
No. 3	700	25.1	65	106.2	45.4	37.5	78.9	242.1	102.0
No. 4	635.6	15	....	126.0	43.5	22.5	67.9	245.6	115.1
No. 5	610	20	14.1	102.2	43.4	30.3	49.6	245.5	104.9
Mean	699.1	19	52.1	120.7	45.6	31.2	69.3	251.5	111.4

SAMPLES FROM MARGINAL SPRINGS IN SOUTH SPRING RIVER.

[Parts per million.]

	Total solids.	Silica (SiO_2).	Water.	Calcium (Ca).	Sodium (Na).	Chlorine (Cl).	Carbonic acid (CO_3).	Calcium magnesium sulphate.
No. 1	700	26.9	49.4	80.9	23.5	46.7	121.6	351
No. 2	730	30.8	50.0	72.1	51.0	63.0	107.9	355.2
No. 3	690	22.3	53.0	76.1	16.8	27.9	114.9	378
No. 4	790	16.0	63.4	72.1	32.1	48.5	107.9	450
No. 5	1,140	50.0	94.0	80.1	62.1	63.7	119.9	670
No. 6	1,070	41.5	85.5	80.1	52.8	81.2	119.9	609
Mean	853.3	31.2	65.9	92.3	44.7	66.2	115.4	468.9

SAMPLES FROM BOTTOM SPRINGS IN SOUTH SPRING RIVER.

	Total solids.	Silica.	Water.	Ca.	CO_3.	Na.	Cl.	Calcium magnesium sulphate.
No. 1	680	27.2	51.8	111	74	18.9	29.1	368.0
No. 2	650	13.4	51.2	106.2	70.8	17.1	26.3	365
No. 3	700	9.6	57.0	106.2	70.8	19.9	30.5	406
No. 4	670	20.5	52.5	106.2	70.8	18.7	28.8	372.5
No. 5	620.8	....	27.8	109.2	72.8	17.3	26.7	367
No. 6	700	50.2	55.0	106.8	71.2	16.9	25.9	374
No. 7	690	38.3	55.0	106.2	70.8	18.0	27.7	374
No. 8	700	41.6	53.9	105.6	70.4	17.5	27.0	384
No. 9	690	45.0	51.0	112.5	75.0	17.5	27.0	362
Mean	678	27.4	50.5	107.8	71.8	18.0	27.7	374

The composition of the artesian water at Roswell differs somewhat from that of North Spring River. The total solids are greater and also the amount of sodium chloride. The following analysis will show the composition of the water from a number of representative wells at Roswell.

Analyses of water from artesian wells at Roswell.

[Individual data. Parts per million.]

Name and date.	Depth.	Temperature.	Total solids.	Silica.	Ca.	CO_3.	Mg.	Na.	Cl.	Calcium magnesium sulphate.
Crowley:	*Feet.*	*°F.*								
April, 1896	155	64.5	1130	48.0	76.1	113.9	....	160.9	247.6	483.5
April, 1897	155	64.5	930	69.5	70.1	94.9	....	114.5	176.0	395.0
Matthews, Tenn., south of	192	69	680	86.5	56.1	83.9	....	44.7	68.8	340.0
Cahoon:										
1895	227	70.5	860	91.0	76.1	113.9	....	92.2	141.8	315.0
1896	227	70.5	790	35.5	71.1	106.4	3.9	96.5	108.0	316.6
Poe, J. W	237	69	930	46.0	76.1	113.9	....	89.8	138.2	466.0
Judge Lea	225	71	810	20.2	76.9	115.1	....	86.6	133.2	378.0
Captain Clark	256	69.25	1,330	123.0	70.1	94.9	....	154.1	236.9	641.0
Miller, H. M	230	....	1,020	72.3	63.1	106.4	5.67	111.5	171.5	487.5
Prager	218	....	1,170	92.8	73.8	110.4	....	106.0	163.0	576.5
Steam laundry		....	1,290	182.0	68.0	102.0	....	183.6	282.4	472.0
Lea, J. C	331	....	1,160	33.0	70.1	94.9	....	150.0	230.0	572.0

The waters of the larger tributaries of Pecos River from the west, analyzed by Prof. E. M. Skeats, are reported to have the following composition:

Analyses of water of the Hondo, Felix, North and South forks of Seven Rivers, and Penasco rivers.

River and location.	Total solids.	Silica, etc., plus water.	Ca.	Mg.	Na.	CO_3.	SO_4.	Cl.	Temperature.	Remarks.
									°F.	
Hondo (above Pleacho).	1,195	80.7	231.9	59.1	37.1	104.3	622.4	59.5	......	Water fairly clear.
Felix (head spring)	467.2	18.8	107.9	23.9	15.2	125.0	152.0	23.3	64	
South Seven (head spring).	1,320.0	194.9	231.7	74.7	13.8	112.4	670.9	21.3	66.5	
North Seven (head spring).	1,020.0	75.6	164.0	71.8	38.9	102.2	567.7	19.8	......	
Penasco (by Gilberts)	650.0	10.0	136.7	42.8	15.2	107.9	324.3	23.3	......	Trace of hydrogen sulphide.

ORIGIN OF THE ARTESIAN WATER.

The water-bearing formations in the Roswell artesian area outcrop in successive zones on the higher slopes to the west. There they receive their water supply by direct absorption from rainfall and by the sinking of streams (see Pl. IX). The Hondo, Felix, Penasco, and Seven rivers are the most important sources. These streams all rise high on the slopes of the Capitan, Sierra Blanca, and Sacramento mountains, where the rainfall is relatively large. As a result they carry an abundance of water in their upper courses, all of which sinks in the outcrop zone of the porous limestones and the overlying formations and passes underground to the east. After the water has entered these porous formations it is confined by impervious layers of limestone or clay, and under the lower lands to the east it is under considerable pressure.

AMOUNT OF ARTESIAN WATER.

It is difficult to make even an approximate estimate of the total amount of artesian water available in the porous formations underlying the Roswell artesian area. We do not know definitely how much water is absorbed by the permeable rocks in their western outcrop, and we are unable to calculate the amount which escapes through springs and by underflow along Pecos River.

The area drained by the larger western tributaries of Pecos River comprises in all about 4,000 square miles. It lies along the east slopes of the Capitan, Sierra Blanca, and Sacramento mountains. The location and extent of the combined watersheds of all streams supplying water to the underlying formations of the Roswell basin is shown in Pl. IX. The annual precipitation for this general region is comparatively large, ranging from 10 to 20 inches. The mean annual precipitation at Fort Stanton, N. Mex., which lies in the area drained by Hondo River, is about 15 inches. The average for seventeen years prior to 1891 was 19 inches, but from 1901 to 1903, inclusive, the annual rainfall was far below the average. The following table shows the result of observations through a period of nearly five years, ending with 1904:

Monthly and annual precipitation, in inches, at Fort Stanton, N. Mex.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1900	......	......	0.48	0.90	1.09	1.63	1.98	2.18	6.06	1.43	0.40	0.36	......
1901	0.10	......	......	0.90	0.64	1.34	......	1.85	2.00	1.76	2.85	0.95	......
1902	0.05	0.38	0.22	0.00	1.88	0.24	2.28	1.87	0.48	1.81	0.16	0.57	9.94
1903	0.36	0.75	0.17	0.20	0.38	3.41	0.62	1.55	1.55	0.48	0.00	0.05	9.52
1904	0.02	0.10	0.03	0.15	0.14	......	2.87	2.92	6.06	2.68	0.08	0.35	......

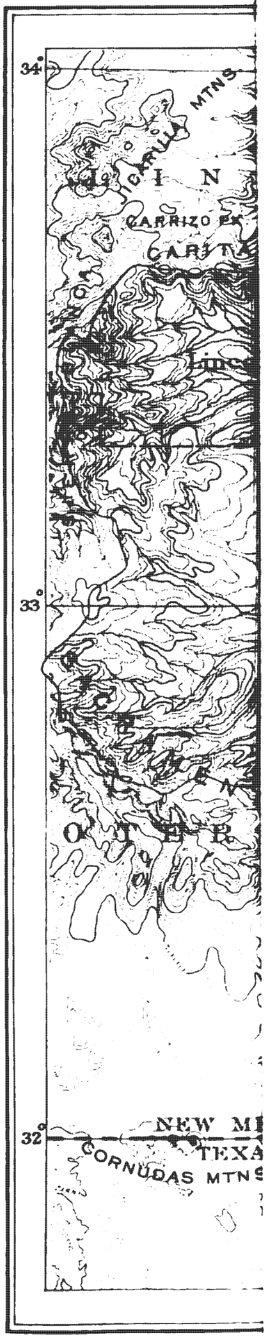
At Lower Penasco, situated on the headwaters of Penasco River, the mean annual precipitation is about 18 inches, as is shown by the following table:

Monthly and annual precipitation, in inches, at Lower Penasco, N. Mex.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1896	0.80	0.40	0.10	T.	T.	2.05	3.56	1.38	1.57	6.01	T.	0.40	16.27
1897	1.40	T.	......	0.50	0.85	0.55	5.60	3.15	1.80	1.05	0.10	0.25	......
1898	0.60	0.25	0.10	1.65	0.70	1.80	7.40	4.00	1.15	T.	0.30	2.40	20.35
1899	T.	0.20	0.35	T.	0	1.70	5.89	1.35	2.90	1.15	1.50	1.05	16.09
1900	0.90	0.30	0.35	0.30	1.70	2.60	4.85	1.95	5.45	1.05	T.	0.60	20.05
1901	......	......	......	0.50	1.15	1.05	6.68	0.97	3.90	......	......	T.	......
1902	0.80	0.05	0.00	T.	0.35	0.30	......	......	......	......	......	......	......

From the above statements it is apparent that the total amount of water which falls during a year of average precipitation throughout the combined watershed of the Hondo, Felix, Penasco, and Seven rivers is necessarily large. Of course a portion of this water is lost by evaporation and run-off, but a considerable amount is absorbed by the water-bearing rocks and becomes available to the east as artesian water. It has not been practicable in the present investigation to compute the total outflow of all the artesian wells in the Roswell basin, but at a liberal estimate this amount would probably be only a small proportion of the quantity absorbed by the water-bearing rocks throughout their western outcrop area. This is clearly shown by the large number of wells which it has been possible to sink in the town of Roswell without materially diminishing the flows of some of the first wells dug. It is possible that the amount of artesian water available around Artesia is not so great as at

U.S. GEOLOGICAL SURVEY



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Roswell, but the only evidence of this is the decrease in pressure of some of the wells at Artesia. The combined watershed of the streams lying west of this part of the basin is larger than that of Hondo River, and according to the Weather Bureau records it has a somewhat greater annual rainfall. For these reasons we would expect the formations underlying the southern part of the basin to contain a large amount of water. While there is evidence of a general decrease in flow throughout the Artesia district, it is probable that this diminution is largely due to the clogging of the pipes with sediment, the escape of water along the outside of the tubing from lower to higher horizons, and various other causes which are known to affect the flow of artesian wells.

It is believed that there is no cause for fear that the water supply throughout the northern part of the Roswell basin will give out or become inadequate for all requirements under proper economy of practice. In the region of Artesia and McMillan not enough wells have been sunk to indicate the amount that the water-bearing beds may be expected to yield.

WASTE OF WATER.

There is pressing need for greater econony on the part of the users of well water throughout the Roswell basin. At Roswell a city ordinance regulates the management of all flowing wells, but throughout the remainder of the district no restraint whatever is placed upon the management of the wells, and, with very few exceptions, they are allowed to flow continuously. A small portion of this water is stored in artificial reservoirs, but by far the greater part runs off into pools, evaporates and seeps away on uncultivated lands, or runs directly into Pecos River. In one case noted a ditch leads from the well directly to the river, a distance of one-half mile, and it is not an unusual thing to find water flowing from the wells to low, marshy lands adjacent to the river, where by underflow it soon reaches the main channel. Formerly many of the wells were not even furnished with reservoirs, and the water was carried by laterals directly to the fields during the irrigating season, and at other times was allowed to flow off through wasteways.

Nearly all the wells that are being constructed at the present time in the southern part of the basin are to be furnished with reservoirs ranging in capacities from 6 to 24 acre-feet, which are filled as often as necessary during the irrigating season. Even these commendable provisions are quite ineffectual in the case of wells not provided with valves, as they conserve only a relatively small portion of the total flow. An effort is now being made by a few of the well owners in the vicinity of Artesia to provide each well with a suitable valve, so that, when the water is not in use and the reservoir is full, the flow can be shut down. There is a general prejudice among well owners against shutting off the flow, as they fear that it will decrease the efficiency of the well. It is true that in a few cases wells have been damaged in this way, but where they were properly constructed the per cent injured is very small.

SHALLOW WELLS.

More or less water is obtained throughout the Roswell basin at depths varying from 25 to 200 feet. The water usually occurs in coarse gravel of the unconsolidated deposits. The supply appears to be inexhaustible, and in many cases the water is used for irrigation purposes. Outside the area of flow from Roswell to Hagerman there are a number of wells 75 to 100 feet deep, which furnish 5,000 to 7,000 gallons of water a day. The water is generally pumped with windmills. In the vicinity of Roswell a few deep nonflowing wells are provided with gasoline engines. A gasoline pumping plant on Sherman's farm, at Roswell, is shown in Pl. VIII, *B*.

Bordering the area of flows throughout the Roswell basin there is a zone of irrigable land 3 to 5 miles wide, in which water would probably rise in deep wells to within 100 feet of the surface, so that it could be profitably pumped for irrigation. The approximate limits of this area are shown on Pl. VI.

The following list gives the principal features of a number of shallow wells in the northern part of the Roswell basin:

List of shallow wells in the Roswell basin.

Name of owner and location.	Depth.	Amount pumped per day.
	Feet.	*Gallons.*
Albrecht, E. O., NW. ¼ sec. 32, T. 12 S., R. 25 E	88	....
Altebery, J. R., S. ½ NW. ¼ sec. 28, T. 11 S., R. 23 E	208	....
Bethel, H., W. ½ NW. ¼ sec. 1, T. 17 S., R. 25 E	72	....
Bowers, J. S., SW. ¼ sec. 23, T. 11 S., R. 23 E	132	7,000
Brink, F., E. ½ NW. ¼ sec. 15, T. 11 S., R. 23 E	125	7,000
Clark, J. H.:		
NW. ¼ sec. 18, T. 17 S., R. 26 E	38	....
SE. ¼ SE. ¼ sec. 12, T. 17 S., R. 25 E	100	....
Com, W. W., SW. ¼ SW. ¼ sec. 35, T. 11 S., R. 25 E	42	....
Costa, N., SE. ¼ SE. ¼ sec. 8, T. 11 S., R. 24 E	27	6,000
Gilbert, C. H., NE. ¼ NE. ¼ sec. 21, T. 11 S., R. 25 E	360	....
Gishwiller, J. A., SW. ¼ sec. 18, T. 11 S., R. 24 E	71	8,000
Hobbs, J. W.	58	....
Hobbs & Hanney, SE. ¼ sec. 2, T. 11 S., R. 23 E	77	5,000
Hortenstein, SW. ¼ sec. 23, T. 12 S., R. 25 E	102	6,000
Miller, F., T. 11 S., R. 23 E	85	2,000
Millheiser, P.:		
SW. ¼ SW. ¼ sec. 7, T. 11 S., R. 24 E	30	3,000
SW. ¼ NE. ¼ sec. 7, T. 11 S., R. 24 E	175	5,000
Paulson, P. O., NW. ¼ sec. 30, T. 13 S., R. 26 E	58	....
Peck, J. C., SE. ¼ sec. 27, T. 11 S., R. 23 E	160	5,000
St. John, J. A., SE. ¼ SE. ¼ sec. 18, T. 11 S., R. 24 E	60	7,000
Saunders, J. P., SW. ¼ NW. ¼ sec. 8, T. 13 S., R. 25 E	155	....
Smith, E. L., T. 11 S., R. 23 E	129	7,000
Stockard, J. W.:		
SE. ¼ SE. ¼ sec. 23, T. 11 S., R. 23 E	150	7,000
NW. ¼ SE. ¼ sec. 23, T. 11 S., R. 23 E	92	6,000
Turner, W. P., NE. ¼ NE. ¼ sec. 7, T. 11 S., R. 24 E	30	6,000
White, G. A., sec. 18, T. 14 S., R. 26 E	84	....
Williams, O. L., NE. ¼ sec. 7, T. 12 S., R. 25 E	103	....

IRRIGATION.

Irrigation has been practiced to some extent in the Roswell basin since the first settlements were made, but prior to 1889 only a few small farms were irrigated. The permanent water supply in the vicinity of Roswell was the first to be utilized. Here a number of small ditches were dug, and by extending these ditches from time to time the present Roswell irrigation system has been developed. The Northern canal system, which irrigates the territory south of Roswell, was built by a development company as a part of a large irrigating project, designed to irrigate Pecos Valley from Roswell to the Texas-New Mexico line.

Roswell system.—A number of ditches have been constructed from the head springs of Middle and South Berrendo and North and South Spring rivers, which furnish water for the land along their valleys. The surplus water of these ditches is directed into the Northern canal to be used for irrigation farther down Pecos Valley.

Northern canal.—This canal extends from Hondo River at a point about 5 miles east of Roswell to near Lake Arthur, a distance of about 35 miles, and irrigates a large district of well-improved farming land in the vicinity of Hagerman. Besides receiving water from

the Berrendo and North and South Spring rivers, the Northern canal is supplied with water to some extent by artesian wells. Though the water of the Northern canal is highly mineralized from the large amount of seepage water which it receives in the vicinity of Roswell, the harmful salts apparently are not present in sufficient quantities to affect plant growth. The following analysis made by Prof. E. M. Skeats shows the average condition of the Northern canal water:

Analysis of Northern canal water.

	Parts per million.
Sodium (Na)	256.1
Sodium and potassium sulphates	230.0
Magnesium (Mg)	50.4
Calcium (Ca)	428.0
Chlorine (Cl)	393.9
Carbonic acid (CO_3)	101.9
Sulphuric acid (SO_4)	349.7
Silica, alumina, and iron ($SiO_2Fe_2O_3Al_2O_3$)	20.0
Water of crystallization	190.0
Total solid	2,020.0

Hondo project.—Preparations are now being made by the Government to store the flood waters of Hondo River for the purpose of irrigating lands along Hondo Valley above Roswell. The location of the proposed reservoir is in a high natural depression on the divide between Blackwater Arroyo and Hondo River. The surface rock in the vicinity is a massive blue limestone, weathering to light gray, underlain by alternate layers of gypsum and red and yellow clay. The bedding was originally uniform, but surface waters have dissolved the gypsum, causing a settling of the beds in the bottom of the reservoir and considerable local distortion around its rim. A number of borings were made with a diamond drill in the bottom of the reservoir, in order to determine the character of the underlying rocks. The following is a record of one of these borings:

Record of diamond-drill boring, Hondo reservoir site, New Mexico.

	Feet.
Clay	0 -11.1
Broken limestone	11.1-22
Clay	22 -25
Cavity	25 -30
Broken rock cavities	30 -64.4
Gypsum	64.4-70.2
Clay	70.2-71.9
Cavity	71.9-73.4
Loose rock	73.4-76.8
Gypsum	76.8-79.8
Clay	79.8-80.2
Limestone	80.2-88.4
Gypsum	88.4-91.8

ARTESIAN IRRIGATION.

The use of artesian water for irrigation in the Roswell area began soon after the first flowing wells were obtained, and it has been gradually increasing ever since. Irrigation from the waters of Hondo and North and South Spring rivers has been practiced, as previously stated, for many years, and the use of artesian water was not resorted to until most of the surface waters of the region had been appropriated. There are now several farms in the vicinity of Roswell that depend entirely on artesian water for irrigation, and to the south nearly all the land included in the area of flow has been filed on with the intention of reclaiming it by artesian irrigation. Many of the farmers in the vicinity of Roswell who have practiced artesian irrigation for several years have obtained results which are highly satisfactory. This has caused considerable interest and enthusiasm among those living farther south in the less developed portions of the basin, and in this region

many large wells are now being sunk, which will be used exclusively for irrigation. Many of these wells are being provided with storage reservoirs, so that a larger amount of water will be available during the growing season.

Among many landowners throughout the area there is a tendency to overestimate the amount of land that can be irrigated from an ordinary artesian well. According to conservative estimates made by irrigators who have had considerable experience in this locality a flowing well with a yield of 450 gallons per minute, provided with a suitable storage reservoir, will irrigate 30 acres of alfalfa or 70 acres of orchard. In order to accomplish this, however, the land must have the proper slope and the soil must be of uniform texture. Alfalfa requires more water than any of the staple crops. Under ordinary conditions 30 inches per year is sufficient, but if the land is irrigated during the winter a larger quantity is required. If this amount of water is properly applied, three or four crops may be cut, the harvesting period ranging from May to the latter part of August. An average yield of alfalfa is 1 ton to the acre for each cutting.

It is difficult to make definite statements regarding the irrigation of orchards in this locality. It is accomplished in many different ways, depending mainly on the age and condition of the trees. In many instances vegetables are raised between the rows of trees, and no additional water is required for the irrigation of the orchard. It is generally sufficient to water an orchard once a month during the summer and once, or possibly not at all, during the winter. About 15 to 20 inches of water a year is required.

CLIMATE.

Temperature.—The climate of the Roswell basin does not differ materially in the prevailing aridity from that of the remainder of southern and eastern New Mexico. The temperature of the region is high, with a low relative humidity. The summers are usually long and hot and the winters mild and pleasant. The maximum temperature is 110° and the minimum seldom falls far below zero. The following tables compiled from the records of the United States Weather Bureau give the mean monthly maximum and minimum temperatures of the Roswell district. The observations extend over a period of ten years, 1895 to 1904, inclusive:

Mean monthly temperature at Roswell, N. Mex.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Maximum	71.6	78.6	85.4	90.1	86.9	101.4	99.2	99.4	97.3	87.5	81.5	74.2
Minimum	6.5	5.4	18.4	26	38.5	49.9	56.8	55	41	28.5	17	7.5

Rainfall.—The average annual precipitation at Roswell is 16.6 inches. The greater part of this amount falls during the months of June and July in frequent showers, which, although often violent, are generally local and of short duration. Only a small percentage of the annual precipitation falls as snow. The following record of the monthly and annual pecipitation at Roswell, extending over a period of ten years, shows considerable variation:

Monthly and annual precipitation, in inches, at Roswell, N. Mex.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1895	0.40	0.48	0.02	0.14	2.31	1.28	4.45	2.99	1.09	2.11	0.85	0.07	16.19
1896	0.60	0.14	0.02	T.	0.12	1.97	1.79	0.40	1.89	5.46	0	0.64	13.12
1897	1.12	0	0.59	1.35	3.76	1.42	2.78	2.94	1.25	.44	T.	T.	15.65
1898	0.26	0.86	T.	0.34	1.03	6.05	6.53	2.99	0.69	T.	0.50	1.37	20.62
1899	0.06	0.15	0.06	0.23	0.27	1.62	4.37	1.21	3.64	0.20	3.21	1.54	16.56
1900	0.96	T.	0.50	0.39	1.62	2.13	2.85	1.25	6.53	3.33	0.17	0.07	19.80
1901	0.21	1.15	0.00	0.97	1.04	0.22	3.04	0.60	1.99	2.21	6.15	0.26	17.84
1902	1.24	0.00	0.83	T.	0.70	1.03	5.52	1.80	3.08	1.36	0.52	0.50	16.58
1903	0.22	0.96	0.10	T.	0.74	4.37	......	......	0.92	T.	0.00	0.00	......
1904	0.16	0.14	0.00	0.07	1.30	1.80	1.23	0.83	5.10	2.67	0.15	0.30	13.75

The heaviest rainfall ever recorded at Roswell was on October 31, 1901, when 5.65 inches fell in one night, causing considerable damage by flooding.

AGRICULTURE.

The general aridity of the climate renders farming without irrigation impracticable except in a few low-lying areas adjacent to Pecos River. In consequence agriculture is restricted to those portions of the valley where water can be obtained from some of the various canals or from artesian wells. The cultivated portions of the basin at present comprise about one-eighth of the total area included in this report, the remainder being utilized for pasturage of cattle—an industry to which the higher lands are well adapted. The chief products are alfalfa, Kaffir corn, wheat, oats, corn, potatoes, Mexican beans, cantaloupes, celery, and a large variety of garden vegetables. Alfalfa and Kaffir corn are perhaps the largest crops and both are consumed in the region. Fruit raising is a growing industry and many large orchards are found in the irrigated district. Peaches, pears, plums, cherries, and other small fruits have a hardy growth and an abundant yield, but the apple crop is the most important. At South Spring there is a large apple orchard, comprising about 600 acres, from which many thousand pounds of apples are shipped annually. Several large apple orchards have been planted during the last five years, and fruit raising seems destined to become one of the most important industries of the district. The seasons are ordinarily of sufficient length to insure the maturity of all cultivated crops.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

SUMMARY

OF THE

UNDERGROUND-WATER RESOURCES OF MISSISSIPPI

BY

A. F. CRIDER and L. C. JOHNSON

WASHINGTON
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1906

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SUMMARY OF THE UNDERGROUND-WATER RESOURCES OF MISSISSIPPI.

By A. F. Crider and L. C. Johnson.

INTRODUCTION.

GENERAL WATER CONDITIONS IN MISSISSIPPI.

The problem of obtaining potable water in sufficient quantities and at a minimum cost has long engaged the attention of scientific and practical men in both Europe and America. More recently the death of a large number of people from infectious diseases contracted by drinking contaminated surficial water has directed the attention of the general public to the necessity of seeking drinking water from some other source.

In the Gulf Coastal Plain, of which Mississippi is a part, conditions are favorable for reducing to a minimum the death rate caused by drinking impure and unwholesome water. A study of the geologic conditions of the State shows that there is a great thickness of unconsolidated sands interbedded with water-tight clays which dip slightly to the south and west and form large underground reservoirs for the accumulation of water. The State has a heavy annual rainfall, which enters the upturned edges of the open-textured sands, collects in these wide reservoirs, and thus becomes available as well water when the overlying strata are drilled through. Good deep-well water can be obtained over almost the entire State, and there are large areas in which under favorable conditions flowing wells are obtained. The dip of the strata is so regular and the water horizons are so numerous that the areas are small in which potable water can not be found at comparatively shallow depths.

In most of the localities having flowing wells the supply seems adequate for all demands so far made upon it. The low cost of drilling wells in the Gulf embayment has made it possible for even the poorest to have plenty of good water. Railroads, cotton mills, sawmills, canning factories, and various public works have found the deep-well water cheaper and better than surficial water. Along the southern coast in the rice area water for irrigation is in many places obtained from artesian wells.

FIELD WORK.

The field work for this report was done by Messrs. L. C. Johnson and A. F. Crider. Mr. Johnson has been engaged for a number of years in geologic work in Mississippi and Alabama for the Alabama Geological Survey, and later for the United States Geological Survey. The collection of well records in this report was to a great extent made by him. In the fall of 1904 Mr. Crider, under the supervision of Messrs. E. C. Eckel and M. L. Fuller, in charge of geology and water resources, respectively, collected further data on the geology and its relation to the underground waters of the State. The present report was prepared by Mr. Crider from the data obtained from these sources. Much valuable information was also obtained from owners of wells, drillers, and others interested in the work.

GEOGRAPHY.

Mississippi occupies the central position of the States bordering on the Gulf of Mexico, with Alabama and Florida to the east and Louisiana and Texas to the west. It has a total area of 46,810 square miles, with an extreme length from north to south of 330 miles and a maximum width of 188 miles. It has 85 miles of coast line on the Mississippi Sound and a water frontage of 500 miles on Mississippi River.

The southern third of the State is largely covered with a fine growth of long-leaf yellow pine, which is being rapidly removed for lumber. There is still much valuable hard wood and short-leaf pine in the northern portion of the State. Besides the large areas of virgin timber, much land in the State that was in cultivation before the civil war has since been abandoned and now bears second-growth timber of a poorer quality, consisting principally of short-leaf pine.

TOPOGRAPHY.

With the exception of a very small area in the northeast corner, the entire State of Mississippi lies in the Coastal Plain. There is a gentle slope southward and westward from the region of northern Mississippi, where the highest hills rise about 700 feet above sea level.

The larger streams, such as the Tombigbee on the east and the Mississippi on the west, have cut out large valleys and have worn them down almost to base-level. The smaller streams have been constantly cutting back from the larger until there are but few undrained interstream areas. The configuration of the State, therefore, has been greatly changed, so that it can be separated into distinct topographic subdivisions.

The prevailing unconsolidated material of the various geologic formations has affected the topography of the State but little. The rivers and smaller streams in many cases flow at right angles to the strike, thus cutting across the changing strata of the various formations.

Tennessee River hills.—The foothills of the Appalachian Plateau reach their southwestern terminus in the northeast corner of Mississippi, near Tennessee River. The streams flowing into the Tennessee are short and have a steep gradient. They have thus cut deep channels into the older Carboniferous rocks, which stand out as high cliffs and form the most picturesque scenery of the State.

The western side of the Tennessee River hills slopes more gently to the Tombigbee Valley. The elevation of the ridge between the Tennessee and the Tombigbee is 600 feet or more. The elevation of the river at Columbus is 146 feet above sea level. This gives a total descent of over 450 feet for the waters of the western slope of the Tennessee River hills.

Tombigbee Valley or Northeast Prairie.—The Tennessee River hills and the high ridge extending north and south from the town of Pontotoc were once continuous across the broad valley of the Tombigbee. There is still a line of highland connecting the hills of the northeast with the plateau of the central part of the State, as the following elevations will show: Iuka is 460 feet above sea level and to the south the hills rise still higher, forming the divide between Tombigbee River and the waters of the Tennessee and Hatchee. The towns of Booneville and Ripley are situated near the crest of the divide; the former is 532 feet, the latter 525 feet, above sea level. The broad valley of the Tombigbee, commonly known as the "black prairie," has an elevation ranging from 179 feet at Macon to 532 feet at Booneville. The Tombigbee Valley is, therefore, a broad spoon-shaped trough with a high rim on three sides.

North-central plateau.—The large area occupying the north-central part of the State is a plateau sloping gently westward and southward from the divide between the Tombigbee basin on the east and the Mississippi and Pearl River basins on the west. The region has been greatly dissected by streams which still have deep, narrow valleys.

The plateau ends very abruptly along its western border, which is distinctly marked by a line of hills or bluffs extending from Memphis, Tenn., to Vicksburg, Miss., along the eastern rim of the Yazoo Delta. The bluffs stand 200 feet or more above the low-lying delta to the west. The difference in elevation of the Yazoo Delta and the central plateau to the east has caused the streams in central Mississippi to cut the bottoms of their channels more rapidly than they have widened their valleys.

The divide between the waters of the Tombigbee and Hatchee basins, which extends westward from the southern part of Tishomingo County to Ripley, continues unbroken with a gentle westward slope through central Tippah, northern Marshall, and De Soto counties almost to Mississippi River. The highest known elevation along this divide is near the town of Holly Springs, where the Illinois Central Railroad reaches 625 feet above sea level. The elevation of Olive Branch, in eastern De Soto County, is 421 feet, and near Horn Lake, which is but 12 miles from the Mississippi, the elevation is 340 feet.

Extending north and south, or at right angles to the east-west divide, is the Pontotoc divide, which separates the waters of the Tombigbee basin from those of the Mississippi, Pearl, Leaf, and Chickasawhay rivers. The Mobile, Jackson and Kansas City Railroad follows the ridge from Pontotoc to Louisville. Here the ridge turns southeast and passes into Alabama at the southern border of Lauderdale County. This divide has a general elevation throughout the State of about 500 feet.

Yazoo Delta.—The vast alluvial bottom known as the Yazoo Delta contains over 6,000 square miles lying between Mississippi River and the line of hills extending from Memphis through Batesville and Yazoo to Vicksburg. South of Vicksburg the Mississippi has a sharp wall on the east bank and a broad valley on the Louisiana side.

There is but little relief over the entire delta area. The larger streams, such as the Yazoo, Coldwater, Tallahatchie, Sunflower, and the Mississippi on the western boundary, have built up their banks by continual deposition so that the highest elevations are near the rivers, and there are gentle slopes to the interstream areas. When the Mississippi overflows the delta the banks of the larger streams are the last to be submerged.

There is a gradual slope southward from the Tennessee boundary, at an elevation of 217 feet, to Vicksburg, which is 94 feet above sea level. An east-west line from Greenwood to Greenville shows very little variation in the three known elevations. That at Greenwood is 143 feet, while the towns of Leland and Greenville are each 125 feet above sea level. This shows a very slight westward slope.

Jackson prairies.—Between the roughly carved region of the north-central plateau and the long-leaf-pine hills to the south is a belt of country known as the Jackson or central prairies. Its extent coincides with the area underlain by the Jackson formation, which is described on page 10.

The surface is more rolling than that of the regions to the north and south. Between Pearl River southeast of Canton and the town of Vosburg are large areas of level prairies covering hundreds of square miles. The streams on the north side of this belt as far east as Newton flow north and northwest to the Pearl; the streams on the south side flow to Strong, Leaf, and Chickasawhay rivers.

The elevation along the crest of the divide ranges from 426 feet at Vosburg to 475 feet at Forest. There is a gentle southward slope of less than 2 feet per mile from Louisville, which is 552 feet above sea level, to the Jackson prairies. The western third of the Jackson prairies is much lower than the region to the east. This is due to the valleys of Pearl and Big Black rivers. These rivers opposite Canton approach within 16 miles of each other, but the Big Black flows at a much lower elevation.

Long-leaf-pine hills.—The region from the Jackson prairies to the Gulf presents a diversity of topographic features. In many particulars it is analogous to the north-central plateau. The highest elevations rise more than 500 feet above sea level. The largest streams flow in very narrow valleys and are but little above sea level. The smaller streams are short and have steep gradients.

The interstream areas west of Pearl River have a maximum height of perhaps 600 feet. The Illinois Central Railroad from Beechgrove to Magnolia has many points above 425 feet in elevation, and reaches a maximum of 487 feet 5 miles north of Hazlehurst. This high plateau extends westward to within 10 to 15 miles of Mississippi River.

The region east of Pearl River is much lower except a small area south of Brandon, in southern Rankin and Simpson counties. Chickasawhay, Leaf, and Pascagoula rivers are but little above sea level, while the areas between have a maximum elevation of only 350 feet.

GENERAL GEOLOGY.

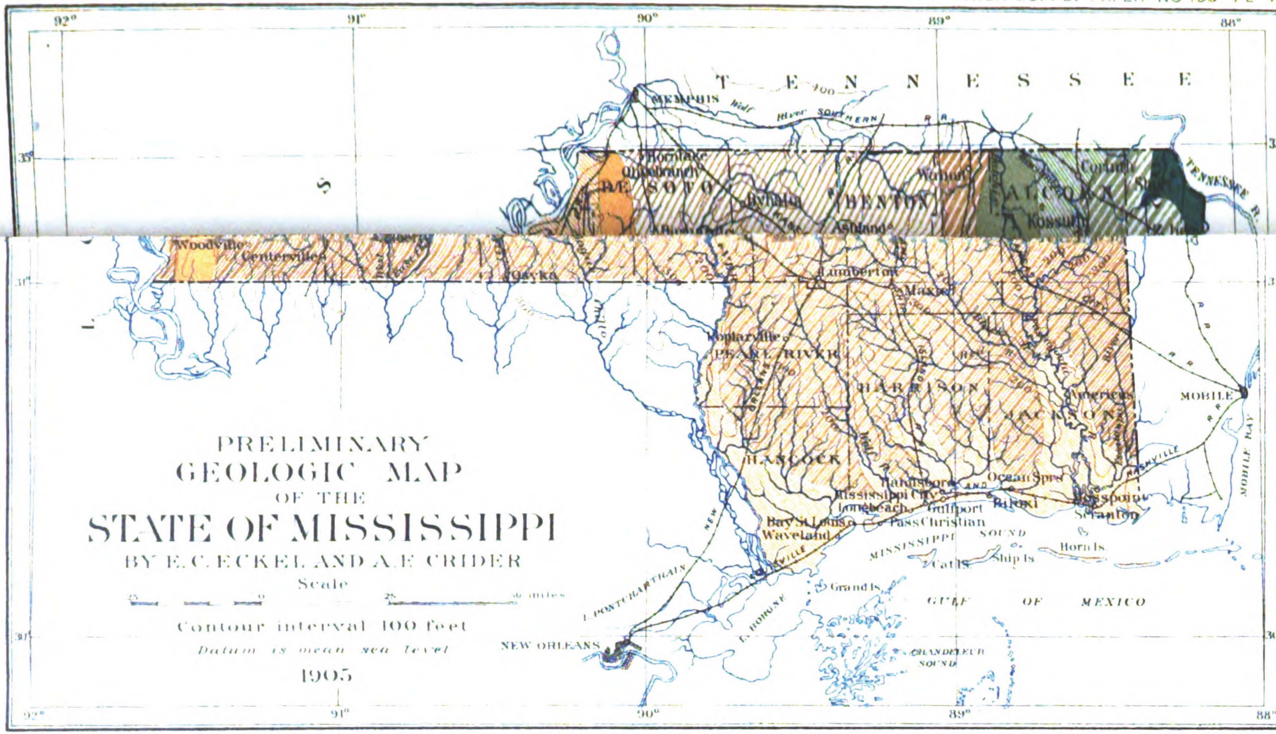
STRATIGRAPHY.

Though the geologic structure of Mississippi is very simple, the details of the stratigraphy are hard to make out. This is due largely to the extent to which the underlying rocks are covered by the more recent deposits, such as the alluvium and the "orange sand" or Lafayette formation.

The older rocks of the State represented by the Devonian and Carboniferous form the old sea floor, on which at a much later period the more unconsolidated beds belonging to the Cretaceous were laid down. The older rocks underlie the entire State, but come to the surface only in the northeast corner along Tennessee River.

The newer rocks outcrop south and west of this older mass in successive, roughly parallel bands. All dip slightly to the southwest, so that if an observer should start in Tishomingo County and travel through the State either south or west he would find himself continually passing over newer and newer series of rocks, until he finally reached the very recent alluvial deposits which fringe the Gulf and Mississippi River. The newer rocks, overlapping the older in the northeast, cover them to a greater and greater depth to the west and south. At the town of Corinth the hard rocks were struck at a depth of 450 feet from the surface, but, so far as known, no wells west or south of this have entered the hard Paleozoic rocks.

The Cretaceous and Tertiary sediments were deposited in a vast trough comprising the present States of Mississippi, western Tennessee and Kentucky, and southern Illinois on the east side; and southeastern Missouri, eastern Arkansas, Louisiana, and southeastern Texas on the west. To the east, north, and west of the embayment was higher land, which was worn down by erosion and from which material was carried by the streams and deposited in the trough-like embayment. Thus we have a series of strata dipping to the south and west on the east side of the embayment and to the east and south on the west side. The fine artesian-water basin in this region is due to the sandy, unconsolidated character of the sediments and the gentle slope of the sea floor on which they were deposited.



LEGEND

QUATERNARY

Tuscaloosa sands and clays

PALEOZOIC

Devonian and Mississippian shales sandstones, and limestones

JULIUS BIEN & CO. LITH. N.Y.

The following section shows the geologic groups which are exposed in Mississippi and the relation of one group to another, the newest formations being at the top of the table and the oldest at the bottom:

General geologic section of Mississippi.

System.	Series.	Formation.	Water supply.
		Recent alluvium. Sands, silts, and loam.	Large supply of unwholesome water.
		Yellow loam. Surface loam or brick clays of northwestern Mississippi.	Little or no water.
		Fossiliferous loess. Gray to buff-colored calcareous silt, containing land shells.	
Quaternary		Port Hudson. Greenish to bluish clays, with interbedded sands. Calcareous concretions in lowest members.	Plenty of soft but unwholesome water.
		Lafayette. Red to yellow sands and iron-stained pebbles. Sands in places containing large amount of clay.	Good, wholesome, soft water. Source of shallow wells and springs in north-central and southern Mississippi.
Tertiary	Miocene?	Grand Gulf. Gray aluminous sandstones, interbedded with white to gray plastic clays in northwest; darker-colored clays containing lignitized wood and vegetable matter in southeast.	Source of flowing and nonflowing wells and numerous mineral springs.
	Miocene	Pascagoula. Calcareous sands, containing numerous fossils.	Probable source of flowing wells along the Gulf coast.
	Oligocene	Vicksburg. White, yellow, and blue crystalline limestone, interbedded with thin layers of indurated calcareous clay.	Little or no water.
	Eocene	Jackson. Gray calcareous clays, lignitic clays with gray siliceous sands, and some greensand.	Small amount of highly mineralized water.
		Claiborne group: Lisbon formation. Calcareous clays and greensands.	Little or no water.
		Claiborne group: Tallahatta buhrstone. Aluminous and quartzitic sandstones, greensands, and clay stones.	Plenty of water, which is sometimes highly mineralized. Source of deep flowing and nonflowing wells in the central and southern parts of the Yazoo Delta; also in Clarke County.
		Wilcox. Highly stratified sands and clays of various colors, with some beds of greensand marl.	Large supplies of soft water. Source of deep-well waters in the northern area of the Yazoo Delta. Water frequently mineralized.
		Midway group: Porters Creek. Gray aluminous clays.	Little or no water.
		Midway group: Clayton. Limestone, sands, and clays.	
Cretaceous		Ripley. Limestones, sandstones, and clays.	Plenty of wholesome water. Source of flowing wells in Pontotoc and Union counties.
		Selma chalk. White chalky limestone and blue calcareous clays.	Occasional springs of hard water.
		Eutaw. Siliceous sands and clays, with some greensand.	Water plentiful. Source of flowing and nonflowing wells over Selma chalk area. Water frequently impregnated with iron.
		Tuscaloosa. Variegated sands and clays.	
Carboniferous		Sandstone, limestone, and clays	Numerous fresh-water springs; wells uncertain.
		Limestone and chert	
		Siliceous chert	
Devonian		Dark limestone and shale	Little or no water.

DESCRIPTION OF FORMATIONS.

DEVONIAN.

The lowest rocks found in the State consist of a series of dark-blue limestones, thinly bedded fine-grained sandstones, and shales representing the Devonian. The lowest visible strata are a series of beds of dark-blue limestone 45 to 50 feet thick, above which come 10 feet or more of highly siliceous chert, which has weathered into a sponge-like mass and contains numerous fossils. These Messrs. Schuchert and Kindle have determined as equivalent to the "New Scotland" beds, which lie at the base of the Devonian in New York. The fossiliferous cherty layer is overlain by 75 to 80 feet of black, and in places blue, shale containing more or less iron pyrite.

The Devonian rocks are of no importance as water carriers, but they act as an impenetrable barrier to the surficial waters and their line of outcrop is marked by numerous springs. The outcrop, which is limited in this State, forms the bed rock and steep cliffs along the west bank of Tennessee River and can be traced for a short distance along Yellow Creek, Indian Creek, and other small streams flowing into the Tennessee. The tops of the hills between these streams are covered with Cretaceous sediments. The shaly material which was struck in the Corinth well perhaps belongs to the dark-colored shales coming above the fossiliferous horizon along Yellow Creek.

CARBONIFEROUS.

Above the Devonian lies the Mississippian (Lower Carboniferous) series of limestones, sandstones, and shales. The thickness of these beds is not known, but it is perhaps 700 or 800 feet. They are but little disturbed and have a perceptible dip to the south and west. The Carboniferous represents the southwestern extremity of the southern Appalachian Plateau, whose southern and western slopes are overlapped by the younger formations.

The heavy-bedded limestones in many places interbedded with shales, cause numerous springs along the watercourses. The coarse-grained sandstone at the top of the Carboniferous forms a reservoir for the accumulation of water, but in numerous places it has been cut through to the underlying limestone, and excellent springs are found at its base. Where there is no leakage, good water is obtained by drilling through the sandstone.

In the Carboniferous area good water is obtained at the base of the overlapping surficial red and yellow sands and from numerous springs, so that very little attention has been given to the deeper waters.

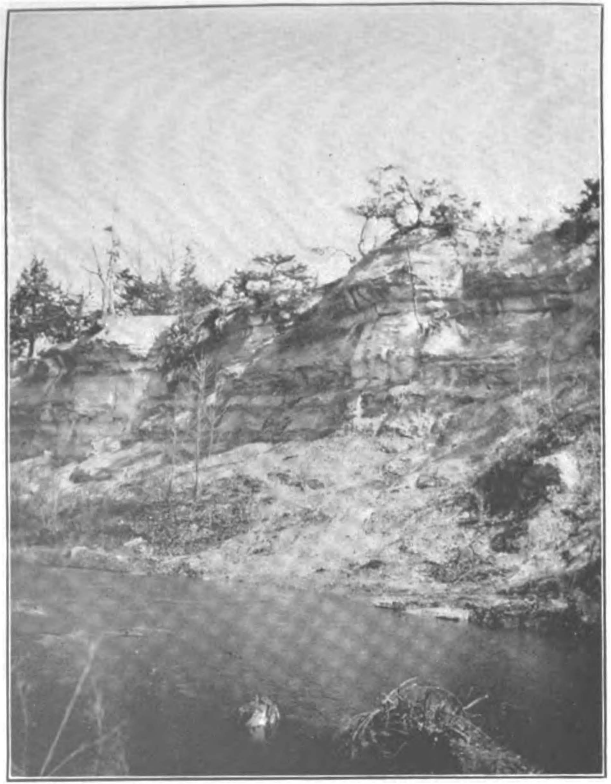
The area of the Carboniferous outcrop is somewhat greater than that of the Devonian, but it is likewise confined to the stream valleys in the eastern and southern portions of Tishomingo County, in southeastern Prentiss, and in northeastern Itawamba County. Over a large area along the eastern border of the Lower Cretaceous the Carboniferous lies near the surface, but the westward dip of the old sea floor and the constantly increasing depth of the Cretaceous to the west soon carry the Carboniferous strata hundreds of feet below the surface.

CRETACEOUS.

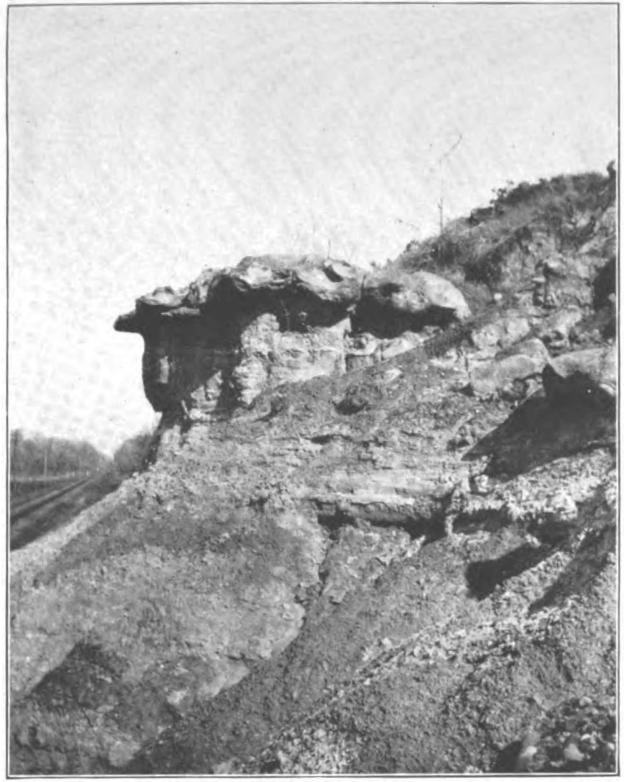
TUSCALOOSA FORMATION.

Between the uppermost member of the Carboniferous and the next overlying formation met with in northeastern Mississippi there is a marked unconformity. This overlapping formation is well shown near Tuscaloosa, Ala., from which it has been named. In the Tuscaloosa formation and in those of still younger age the important water horizons of the State are found. In Tennessee the Tuscaloosa and the overlying Eutaw have been grouped together and described under the name of "Coffee" sands.

In its lower portion the Tuscaloosa is composed of various colored clays, lignite, and lignitic clays; in the upper part are variegated, cross-bedded sands and sandy clays. The clays at the base are so compact and free from sand that they serve to retain or check the descending waters.



A. OUTCROP OF SELMA CHALK, THE CAP ROCK OF THE WATER-BEARING EUTAW SANDS.



B. TALLAHATTA BUHRSTONE CAP ROCK, OVERLYING LOOSE SILICEOUS SAND.

The sands of the upper portion supply the water of this formation. They do not extend in one continuous bed from the top to the bottom, but there are various irregular horizons throughout the formation, which supply water. The irregularity is due to the noncontinuous beds of clay, which are not persistent throughout the formation.

The thickness of the formation is estimated from well borings in western Alabama to be 1,000 feet, of which 300 to 400 feet or more are the compact clays at the base. In wells at Corinth, Miss., the hard rocks of the old sea floor were encountered at 450 feet. At a depth of 150 feet the upper sands of the Tuscaloosa were found, so that the entire thickness of the formation in the north is 300 feet.

The area occupied by the formation is a long, narrow strip east of a meandering line extending north of the town of Columbus to the Tennessee line, including the northeastern portion of Lowndes, the eastern half of Monroe, and a small strip in the eastern part of Prentiss and Alcorn counties, and overlapping the Carboniferous and Devonian in Tishomingo County.

EUTAW FORMATION.

Immediately overlying the Tuscaloosa is the Eutaw formation, which is typically exposed at Eutaw, Ala. The lowest division of the Eutaw is composed of nonfossiliferous, highly micaceous sands and is distinguished with difficulty from the underlying sands of the Tuscaloosa. In the upper portion of the formation the sands become lighter in color, increase in lime carbonate, and are more or less fossiliferous. This marks the beginning of the marine conditions which culminated in the Midway.

The formation is about 300 feet thick near the Alabama line and gradually becomes thinner to the north. The Cox well at Corinth is reported to have struck the Eutaw water-bearing sands at a depth of 90 feet.

The area underlain by the Eutaw formation consists of a narrow belt of country, 5 to 12 miles wide, lying just west of the area of the Tuscaloosa formation. Under the heading "Water horizons of Mississippi" the Tuscaloosa and Eutaw have been taken together as forming one water horizon. These formations are the most important water bearers in northeastern Mississippi, and over large areas west of their outcrop these form the only source of well water.

SELMA CHALK.

The subdivision immediately overlying the Eutaw formation is the Selma chalk or "rotten limestone." In general appearance the Selma formation is a mass of loosely cemented lime carbonate (Pl. II, *A*); but it can be separated into three divisions—(1) the sandy or transition beds at the base, (2) the "blue rock" or unweathered portion, and (3) the "rotten limestone" or chalk near the surface.

The lowest division contains a great amount of free sand, which was washed into the Selma sea from the older land surface to the east. This forms the transition beds from the extreme sandy portion of the Eutaw to the purer lime carbonate of the upper Selma.

The "blue rock" or middle portion contains a large amount of clay, and when freshly exposed is of a bluish color. The clay, which renders the rock impervious, confines the water in the Eutaw sands below, and thus makes it possible to have artesian wells over the eastern Selma area. The clayey portion contains the only suitable material for holding cistern water.

The uppermost division contains a greater amount of lime carbonate and much less clay than the blue rock. It weathers along the rapidly cutting streams into white chalk bluffs, which are exposed along the western border of the outcrop. The porous chalk of the upper subdivision absorbs a great amount of water, and streams soon dry up after a rain.

The thickness of the Selma, as determined by many deep wells throughout the region, is found to vary from about 350 feet near the Tennessee line to 1,000 feet at Starkville. In estimating the thickness of the formation a small allowance must be made for the westward dip of 35 feet to the mile in the south and 10 to 15 feet in the north.

The surface of the outcropping Selma is a level or rolling prairie well adapted to agriculture. It embraces the larger part of Noxubee, western Lowndes, eastern Oktibbeha, the larger part of Clay, western Monroe, the eastern half of Chickasaw, almost all of Lee, western Prentiss, and central Alcorn counties. The west line of outcrop can be traced approximately through the towns of Scooba and Flatwood, and 3 miles west of Starkville to Houston. From here the line bends more to the east, through Troy, Blue Springs, Graham, and Antioch, and 2 miles west of Kossuth to the Tennessee line.

RIPLEY FORMATION.

Above the Selma chalk is the uppermost division of the Cretaceous, which has been called the Ripley formation, and which is made up of three substances. Dark-blue marl, containing abundant well-preserved fossils, occupies the upper part, and thinly bedded marly clays, alternating with sandy limestone, the lower part. The limestones are sufficiently porous to hold water. They come to the surface along the eastern border of the Ripley outcrop, and, with a westward dip of the strata greater than the slope of the surface, a small artesian basin is formed along the headwaters of Tallahatchie River.

The thickness of the formation, estimated by the width of the outcrop with a westward dip of 15 feet to the mile, is at a maximum, 280 feet.

The change from the rolling prairie surface of the Selma to the steep hills of the Ripley is very noticeable. The Ripley formation occupies a much smaller area than the Selma chalk, being widest at the north and wedging out entirely in Chickasaw County, at the town of Houston. From here south to the Alabama border the high hills of the Ripley as found in Tippah, Union, and Pontotoc counties are entirely wanting, except in a small area near the Alabama border. It is well exposed in Alabama, but wedges out in Kemper County, Miss., near the town of Shuqualak. From here to Houston the level "Flatwoods" of the Midway border on the prairie lands of the Selma chalk.

TERTIARY.

MIDWAY GROUP.

Clayton limestone.—The lowest division of the Tertiary is represented in Mississippi by a series of hard crystalline limestones, known as the Clayton limestone, and calcareous sandy marls. The limestone of this formation was referred by Hilgard to the Ripley, but later investigation by Harris and others has, on paleontologic evidence, placed it in the Midway.

The limestone has a maximum thickness of 20 feet near the town of Ripley. It is overlain by 20 to 30 feet of reddish to yellow sandy marl containing lime carbonate, and is slightly fossiliferous. The reddish color is due to a large amount of iron oxide. The color of these sands is very similar to that of the Lafayette, which is described on page 12.

The Clayton outcrop forms a narrow strip of territory from 2 to 6 miles wide, lying just west of the Ripley area. The line of the Mobile, Jackson and Kansas City Railroad follows the outcrop approximately from Middleton, Tenn., to Houston, Miss. From here the outcrop turns in a southeasterly direction west of Starkville and Macon and passes into Alabama southeast of Scooba.

No doubt the sands of the upper division are water bearing, but so far no wells to the west have penetrated the Clayton.

Porters Creek clay.—In Tennessee the name Porters Creek has been given to the clays immediately overlying the Clayton limestone. The calcareous sandy marl of the upper Clayton is overlain by 75 to 100 feet of gray nonfossiliferous clay, which forms the well-known "Flatwoods" area, extending from Tennessee into Alabama. This formation produces very stiff clay soils which are little used in the State for agricultural purposes. Roads through the "Flatwoods" often become impassable during the rainy season.

The Porters Creek outcrop occupies a narrow strip of country extending from Middleton, Tenn., into the State of Alabama, and has a width of 2 to 12 miles. In the north it is hemmed in between the Ripley hills on the east and the Wilcox plateau on the west. South

of Maben the range of hills on the east border of the Wilcox formation rises 100 feet or more above the Porters Creek, and is more distinct than the line between the Porters Creek and the Clayton limestone. The western border is easily traceable from 4 miles east of Maben due south through Oktibbeha County; here the line turns in a more southeasterly direction, running through Shuqualak and Scooba into Alabama.

The Porters Creek clay marks an important horizon between the waters of the Ripley and Wilcox horizons. The rainfall entering the outcropping sands of the Ripley follows these beds, which dip gently to the west. The overlying Porters Creek clay prevents the water from rising, and it is thus confined and given pressure as the reservoir becomes full.

WILCOX FORMATION.

The important division of the Tertiary known as the Wilcox formation occupies a large area of northern Mississippi. It was originally named the Lignitic by Hilgard, and Safford, State geologist of Tennessee, termed it the La Grange group.

The term "Lignitic" as used by Hilgard has been objectionable because it is not a locality name. As used by Safford the term "La Grange" included the present Lafayette and portions of the Cretaceous, so it has likewise been discarded. The present name, Wilcox, was first given in some unpublished work by Eugene A. Smith, State geologist of Alabama, for the reason that typical strata of the former Lignitic of Hilgard are exposed at Wilcox, Ala. The name has been adopted by the United States Geological Survey as the formation name to include the complex mass of sands, clays, lignites, marls, etc., between the Porters Creek clays below and the Tallahatta buhrstone above.

Owing to its more or less sandy character throughout, the Wilcox forms the most important water horizon of northern Mississippi. The coarse-grained, unconsolidated sand beds are often interbedded with seams of lignite and white and chocolate-colored clays. The clays of the upper division, as at Grenada, are very dark and may properly be called shale. In the eastern half of the area loosely bedded sands predominate. The western portion, which is a series of irregularly cross-bedded sands and sandy clays, is separated from the eastern by a more or less regular line of white and chocolate-colored clays, which are used for making stoneware.

The thickness of the group is estimated from the width of the outcrop to be 750 to 800 feet. The deep well at Memphis is reported to have passed through the Wilcox at a depth of 963 feet.

In Alabama, Smith has divided the "Lignitic," the equivalent of the Wilcox, into six members. Each contains one or more marl beds from which distinguishing fossils are obtained. He includes in the "Lignitic" the Porters Creek clays, which in Mississippi are mapped with the Midway.

The Wilcox covers the largest territory of any formation in northern Mississippi. It occupies the entire area lying between the Porters Creek outcrop and the bluffs on the eastern rim of the Yazoo Delta as far south as Grenada. The west edge south of Grenada is a line extending southeast 6 miles east of Winona, west of Philadelphia, and southwest of Meridian.

The entire Wilcox group is very important as a water-bearing formation. The numerous beds of sand interbedded with clays form various water horizons throughout the formation. The shallow artesian wells at Batesville and Coffeeville, begun below the yellow loam and Lafayette, show that there are beds of clay in the upper division of the Wilcox sufficiently persistent and compact to confine the water below the clay and to form artesian basins in the upper Wilcox.

CLAIBORNE GROUP.

The Claiborne is divisible on lithologic grounds into two distinct formations. The lower of these is the Tallahatta buhrstone, or "siliceous Claiborne;" the upper includes the Lisbon beds, or "calcareous Claiborne."

Tallahatta buhrstone.—This formation, called "siliceous Claiborne" by Hilgard, consists chiefly of glauconitic coarse-grained micaceous sandstone, siliceous and aluminous clay

stones, and a white siliceous sandstone that is almost quartzite. The estimated thickness is 350 feet.

The formation outcrops in a belt of territory between the Wilcox and Lisbon beds, and varies in width from 10 miles in northeastern Clarke County to 30 miles in Leake and Winston counties. The eastern line of outcrop is traceable from the Alabama line 4 miles south of Hurricane Creek post-office to Eastville; thence it swings southwest nearly to Sterling, south of Meridian; thence it bends northwest past Battlefield, Philadelphia, Plattsburg, Hinze, and French Camp, 6 miles east of Winona, and west of Grenada. No trace of the Tallahatta has been found north of Yalobusha River.

For the eastern part of the delta and the central portion of the State lying south of the Tallahatta outcrop, this formation forms a very important water horizon. The extensive area underlain by the formation and the porous texture of its materials make it well suited for absorbing a large amount of rainfall. The water-tight clays at the base of the overlying formation confine the water in the Tallahatta buhrstone.

Pl. II, *B*, shows a hard cap rock of sandstone at the top of the section, with loose siliceous sand immediately underlying it. Over extensive areas in the Yazoo bottom flowing wells are obtained when the drill passes through the hard layer of sandstone and enters the sands below. The ledge of sandstone, which varies in thickness from 12 to 30 inches, is very hard, in places almost a quartzite, and often requires several days' drilling to pass through it.

Lisbon formation.—Above the Tallahatta is a series of beds which Hilgard called "calcareous Claiborne" and which will be termed the Lisbon formation. The series is about 150 feet thick, and is composed of calcareous sands and laminated and lignitic clays. The character of the surface is little affected by the Lisbon, which is almost everywhere overlain by the Lafayette.

In Alabama the area underlain by this formation is very limited in extent, but in Mississippi it widens out and occupies the territory from southeastern Clarke to southern Carroll County, varying from 5 to 25 miles in width.

The thick mantle of Lafayette covering the Lisbon area furnishes plenty of good water, and the water-bearing horizons of the Lisbon have therefore not been developed.

JACKSON FORMATION.

In Alabama the Jackson and the succeeding formation, the Vicksburg, have been classed together under the name of St. Stevens. In Mississippi, however, they can usually be separated very readily and will be treated as two distinct formations.

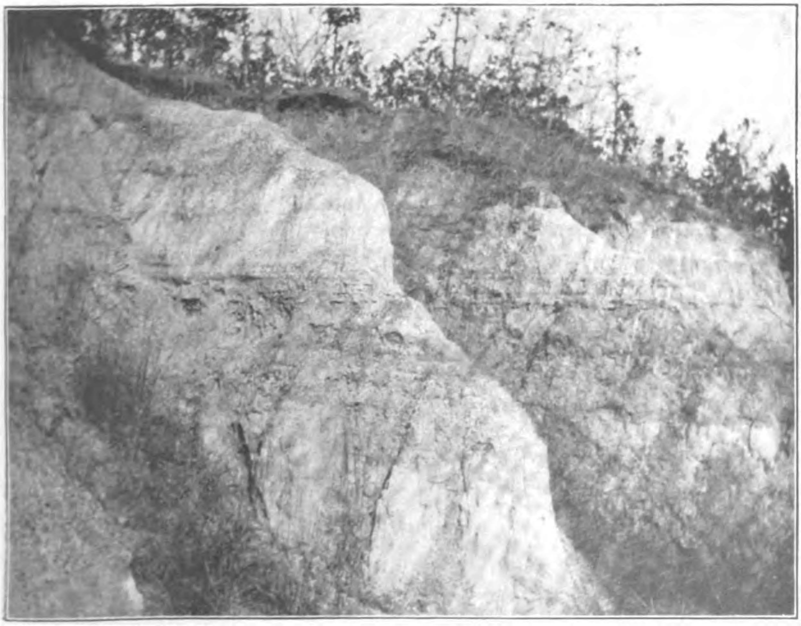
The essential materials of the Jackson group are gray calcareous and lignitic clays and sands. The outcrop occupies a belt of country 10 to 30 miles wide, extending southeast and northwest across the State from Yazoo to the Alabama line north of Waynesboro. The area is known as the "central prairie."

There are no continuous water horizons in the lower or middle Jackson. It is usually barren of water, and when found the water is very impotable. Wells in this region obtain their water either from the base of the Lafayette or from the upper member of the Tallahatta buhrstone. Flowing wells are obtained along the lower streams.

The Jackson has usually been described as "marls" and clays, but recent investigations along the line of contact with the Vicksburg have shown that there are between 50 and 75 feet of yellow, gray, or white siliceous sand at the top of the Jackson. Whether from a paleontologic standpoint this should be considered Jackson or Vicksburg we are unable to say, since no fossils have been found in the sands. They are regularly stratified, showing that they were deposited in a quiet sea with little or no current. In places near the surface the sands are slightly cemented with iron oxide, causing some layers to resist erosion more than others.

Pl. III, *A*, represents the highly stratified character of the siliceous white to gray sands of the uppermost member of the Jackson formation. These sands, which are very porous, are exposed through erosion over large areas in Mississippi and absorb large amounts of water, the water table in such cases very nearly reaching the surface (Pl. III, *B*).

A. JACKSON SANDS, SHOWING CHARACTER OF MATERIAL, AND EROSION AND CATCHMENT CONDITIONS.



B. UPPER PART OF JACKSON FORMATION, SHOWING WHITE OR GRAY SILICEOUS SAND PHASE.

This is the only horizon of the Jackson which may become of any importance as a water-bearer. South of its outcrop there are no deep wells which are known to derive their waters from this horizon, so that its importance in this respect is not known.

VICKSBURG LIMESTONE.

This formation, first studied by Conrad at Vicksburg, occupies a very limited area south of the Jackson. It consists of crystalline limestone in beds varying from 1 inch to 3 feet in thickness, alternating with sandy calcareous strata of marl of about the same thickness. There is a marked difference in the appearance of the different beds of limestone. Those near the surface are soft and yellow, while the more compact beds unaffected by surface weathering are blue. The rapidity with which the limestone breaks down under the action of weathering agents makes it unsuited for building stone or road material. The Vicksburg is of no importance as a water-bearing formation.

PASCAGOULA FORMATION.

E. A. Smith has distinguished along Pascagoula River in Mississippi a series of calcareous sands bearing a Miocene fauna overlying the Vicksburg limestone and underlying the great mass of lignitic sands and clays of the Grand Gulf. He has given it the name Pascagoula formation. No other outcrops have as yet been found in the State, but deep-well borings along the Gulf coast have brought up calcareous sands containing fossils which L. C. Johnson refers to the Pascagoula. It was at first thought that the Pascagoula was younger than the Grand Gulf, or doubtless a fossiliferous horizon in it, but more recent investigation has shown that the Pascagoula clearly underlies the Grand Gulf.

At the type locality of the Pascagoula formation, as well as at Mobile and points along the Gulf in Mississippi, the Pascagoula beds are overlain by Grand Gulf beds; but further field work will be required before the relation of the two series (Grand Gulf and Pascagoula) in other areas can be stated with certainty. Such later work may require a redefinition of the term Grand Gulf. Owing to the limited area of outcrop the formation is not shown on the map. The Pascagoula furnishes an important source of fine artesian water along the coast.

GRAND GULF FORMATION.

The Grand Gulf formation is used in the sense in which it was originally defined by Hilgard. It is, therefore, not a homogeneous series of beds, but may include formations of different age. It is certain, however, that everything here included in the Grand Gulf is newer than the Vicksburg limestone and older than the Lafayette or "orange sand" formation.

The Grand Gulf is made up almost entirely of sandstones and clays. The sandstones are usually but slightly cemented and are made up of sharp grains of silica, with more or less alumina and iron pyrites. The color varies from a pure white to a rusty yellow, the latter resulting from the oxidation of the sulphide of iron. These sandstones are especially common in the northwestern part of the area underlain by the Grand Gulf—that is, northwest of a line drawn from Fort Adams to Raleigh. Southeast of this line sandstones are very rare. Elsewhere the formation consists of bluish to black clays, shales, and unconsolidated sands. The thickness of the Grand Gulf, as ascertained from deep-well borings, is 750 to 800 feet.

The Grand Gulf underlies most of that part of Mississippi south of a line drawn as follows: Starting at the river a few miles south of Vicksburg it runs parallel to and a mile or so south of the Alabama and Vicksburg Railroad, and passes a short distance north of Raymond. Here the boundary line bends rather abruptly southeast, crossing the Illinois Central Railroad between Terry and Byram. It then turns northeast passing through Monterey to Brandon, at which point it finally assumes a southeasterly direction through Daniel, Raleigh, Vosberg, and Waynesboro into Alabama. All the State south of this line is occupied by the Grand Gulf group (except the narrow belt of Port Hudson clays which

border the Gulf coast in Hancock, Harrison, and Jackson counties and are described on page 13.)

The area along the Mississippi from Fort Adams nearly to Vicksburg, and in Lincoln, Copiah, Hinds, Simpson, and Rankin counties, contains the only outcrops of the sandstones. In these localities it alternates with the bluish-tinted clays. At Raymond and Star the sandstones attain a thickness of 15 feet and appear near the summit of the hills, with thinner strata below alternating with semiplastic clays.

The sandstones are wanting south and east of the line mentioned above, and the formation is essentially indurated, laminated sands and clays of various characters, from the white plastic clays to those containing lignitized tree trunks. Beds of lignite are also of frequent occurrence.

Many of the fine artesian wells along the Gulf derive their waters from the Grand Gulf formation. In the region of Hattiesburg and Columbia flowing wells are obtained from its lower division.

LAFAYETTE FORMATION.

Resting unconformably upon all the underlying formations from the Grand Gulf to the Carboniferous is a thin veneering of the Lafayette formation. This is a fresh-water deposit, composed chiefly of dark-red to light-red, coarse, round-grained sand, which in places contains more or less clay and water-worn pebbles. It varies from a knife-edge to 50 feet or more in thickness. The latter thickness is very rare, and it is more often found to be less than 10 feet.

In Tishomingo and Itawamba counties the Lafayette contains large deposits of water-worn pebbles, gravel, flint, chert, and some quartz, extending in a north and south belt 5 to 10 miles wide. Another belt of similar material occurs along the eastern edge of the loess formation, in the counties of De Soto, Tate, Panola, and Yalobusha. The shape of the pebbles is somewhat different in this belt—those of the above-mentioned counties being worn into an oblong egg shape, while here they have a more rounded form; they also contain more quartz. Still another belt, which is practically a prolongation of the western belt, is found in the southern part of the State. The main line of the Illinois Central Railroad runs along the outcrop of the gravel beds from Jackson to the Louisiana border.

The Lafayette was deposited upon a deeply eroded surface of the older formations, which accounts in part for the irregularity in its thickness. Since the deposition of the Lafayette there has been a large amount of erosion, and in many places the whole formation has been removed. In the areas of the Selma chalk and the Porters Creek formation the Lafayette is practically absent. East of the Selma chalk area there is more or less of the Lafayette covering the Eutaw, Tuscaloosa, and Carboniferous. In northern Mississippi, particularly in Marshall and Lafayette counties, where the formation was first described and named, the Lafayette, when present at all, is only a few feet thick, but in many places it is wanting. It thickens to the south, reaching its maximum in southern Mississippi, where it is said to be 200 feet thick. No such thickness, however, was observed in the course of the present work.

In various localities in the State the iron in the Lafayette has cemented the Indian red sands and formed a ferruginous sandstone, which is often mistaken for pure limonite or brown hematite. These deposits are uniformly of very shallow depth, but may extend over considerable areas. The ferruginous sandstone is always formed immediately above a bed of clay or some material which checks the downward flow of water. The water passing through the Lafayette becomes saturated with iron oxide, and, on being checked at the base by the underlying clay, deposits the iron, which cements the sands into a compact mass. This mass is constantly increased by the addition of more iron from the iron-charged waters. Gradually the overlying material is worn away until the ferruginous sandstone is reached, which resists the action of erosion and often forms a scarp along the tops and sides of hills.

Where the Lafayette is thick enough it forms the source of a very desirable and easily accessible supply of potable water. The great amount of sand in the formation forms a natural filter. Many of the springs of the State issue from the base of the Lafayette, where it rests on a bed of water-tight clay, a lignite seam, or limestone.

QUATERNARY.

PORT HUDSON FORMATION.

The formation immediately above the Lafayette has been called the Port Hudson, from the typical exposure at Port Hudson, Miss. It is composed of clays, silts, and unconsolidated sands containing old cypress stumps representing different generations superimposed one upon another. The thickness of the formation, as determined from criteria obtained along the Gulf, is 100 to 125 feet.

The Port Hudson area occupies a narrow belt along the Mississippi south of Vicksburg, the low-lying belt of country between Yazoo and Mississippi rivers erroneously called the "delta," and a small area bordering on the Gulf of Mexico. There is a possibility that the so-called Port Hudson of the Yazoo Delta belongs to a much younger age than the Port Hudson farther south, but for the present it is all mapped as one formation. The vast body of land called the "delta" is but a few feet above the common high-water mark of Mississippi River, and was overflowed in times of very high water until as late as 1884. The investigations of Hilgard have shown that the formation was deposited in a fresh-water embayment during the slow depression of the continent at the close of Glacial time, and that it was not due to the successive overflows of the old Mississippi River.

As far east as Union County, along Tallahatchie River, old inhabitants say the bottom land has been elevated in their lifetime from 2 to 4 feet by successive overflows of the river, a fact easily proved by noting the difference in elevation of the surface on the outside and inside of hollow cypress stumps. The gradual elevation of the bed of the Mississippi in recent years and the vast alluvial deposits show that the Port Hudson formation may possibly be of river origin.

Water in large quantities may be obtained very near the surface over the entire area of the Yazoo Delta by simply driving down a pipe with a strainer attached at the lower end. The large amount of vegetable matter in the Port Hudson sediments causes a very unwholesome drinking water.

FOSSILIFEROUS LOESS.

East of the Mississippi, south of Vicksburg, for a width of 12 to 15 miles, and bordering the eastern limit of the Port Hudson north of this place, is the loess or "Bluff" formation. This is made up of a homogeneous, silty, calcareous loam containing a great number of land shells.

YELLOW LOAM.

Immediately overlying the loess and extending from 25 to 35 miles farther east than the typical loess is the formation which Hilgard has called the "yellow loam." This is an unstratified mass of sandy clay or loam, entirely void of fossils, and of a uniform pale-yellow to light-brown color. East of the calcareous-loess area it forms a thin covering over the Lafayette, when that is present, and has a maximum thickness in northwestern Mississippi of 25 feet. It is also present in the central and southern parts of the State, but is much thinner here than farther north.

RECENT ALLUVIUM.

The most recent strata of the State, occurring along the larger streams, particularly along the Mississippi, have been mapped with the Port Hudson formation.

UNDERGROUND-WATER RESOURCES.

SOURCE OF UNDERGROUND WATERS.

In a series of sands and clays, such as those of the Coastal Plain deposits of Mississippi, the deposition of which took place beneath the salt waters of the ocean, the ground waters are derived from two diverse sources. The salt waters encountered in certain of the deeper wells represent, in all probability, ocean waters which have been retained in the deposits since the accumulation of the latter beneath the sea, while the fresh waters encountered in all of the shallow and in a large proportion of the deep wells have been derived from the rainfall.

RAINFALL.

Mississippi has an average rainfall, according to the Weather Bureau, of about 51 inches, the precipitation varying from 49 inches at the northern edge of the State to 54 inches near

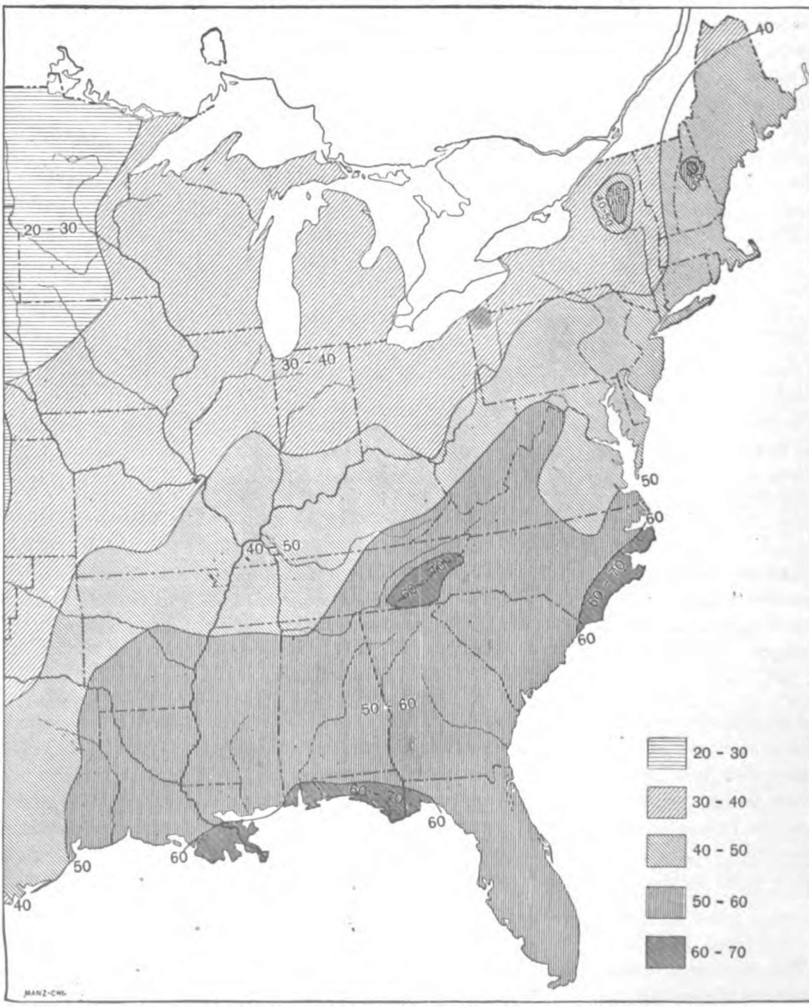


FIG. 1.—Rainfall map of eastern United States.

the coast. The greatest annual precipitation recorded in the State was 101.47 inches at Bay St. Louis in 1900, and the least, 22.49 inches, at Kosciusko in 1889. October and November are usually the dryest months of the year.

Not only does the rainfall vary in total amount from year to year, but the amount in a given district varies greatly. This fluctuation is so large that a rainfall map for a given year has little value. Unfortunately no map showing average precipitation in detail is available, but the general average rainfall for the State and its relation to adjacent areas is shown in fig. 1.

DISPOSAL OF RAINFALL.

The precipitation is taken up mainly in three ways—(1) by evaporation directly from the surface before the rain is absorbed, (2) by direct run-off of the water into the streams without its being first absorbed by the soil, and (3) by absorption into the ground.

A very large proportion, probably 40 to 50 per cent, of the water absorbed by the ground in Mississippi is returned again to the atmosphere by evaporation, either directly from the surface or through the vegetation with which the surface is covered. Of the remaining ground water it is estimated that 1 per cent or less is permanently taken up in chemical combination by the rocks. The rest joins the underground water body occupying the pores and crevices within the rocks and other materials. Where the conditions have been such that water could penetrate the rocks these have long since been filled to saturation up to drainage level, so that practically all the excess of ground water not removed by evaporation finds its way to the valleys and other low spots, where it forms springs or joins the streams by general seepage. The amount thus returned to the streams is a large proportion of the total run-off, the immediate run-off, or that portion of the flow which has never been absorbed by the soil, being estimated at from 5 per cent of the rainfall in the case of certain sandy districts to 33 per cent in an area where the rocks are of several diverse types. It is thought that in the entire State probably not more than 15 per cent is removed by the direct run-off.

Detailed observations of the relation of rainfall to run-off have been made in the Tombigbee and Yazoo River basins. In the former basin, north of Columbus, there was in 1903 a rainfall of 42.69 inches, while the run-off was 19.88 inches, of which 85 per cent, or 16.87 inches, is estimated to have passed through the soil before joining the streams. In a way this may be taken as representing the surplus ground water for the year of the computation. Reduced to gallons, this surplus amounts to about 458,000 gallons per acre. In the Yazoo basin the run-off was 17.41 out of 42.68 inches, the surplus computed in the same manner as above being 402,300 gallons per acre. When it is remembered that a well flowing 100 gallons a minute ranks as a large well, and that the surplus rainfall of every 130 acres would furnish such a well, the vast amount of available ground water, yielding approximately 5 wells to each square mile, or about 234,000 to the State, will be better understood.

DEPTH OF PENETRATION OF WATER.

Water penetrates downward through the pores of the rocks and through cracks, fissures, and other passages. Theoretically it can pass downward until the rock pressure becomes so great that there are no openings, a condition which is estimated to exist at a depth of about 6 miles. As a matter of fact, however, active circulation of ground water takes place mainly in stratified rocks, and then only within a relatively short distance of the surface, usually from 1,000 to 2,000 feet. It is commonly useless to expect unmineralized waters at greater depths.

CAPACITY OF MATERIALS TO HOLD WATER.

The amount of water which can be held by different materials varies greatly. That absorbed by some of the common rocks is shown in the following statement: [a]

Amount of water absorbed by some common rocks.

[In quarts per cubic foot.]

Granite	$\frac{1}{100}$–$\frac{1}{4}$
Limestone (dense)	$\frac{1}{4}$–$1\frac{1}{2}$
Dolomite (including porous limestones)	1– 5
Chalk	4– 8
Sandstone	2– 6
Sand	8–10
Clay	10–12

Rocks have the greatest absorptive power when the grains are of uniform size. Where there is a mixture of fine and coarse grains much less water is taken up. Unfortunately the amount which a given material will yield does not depend entirely on the amount which it contains. For instance, clay, though it has a high porosity, holds water with great tenacity and will yield but little to a well.

RATE OF PERCOLATION.

In general it may be said that the coarser the sand and the smaller the amount of clay the more rapid the rate of movement, but this also depends largely on other factors, such as pressure and temperature. With a given material nearly twice as much water will percolate through a stated area at a pressure of 20 pounds per square inch as will pass through it at 10 pounds. Likewise the percolation is nearly twice as rapid with the water at 100° F. as it is at 50° F.

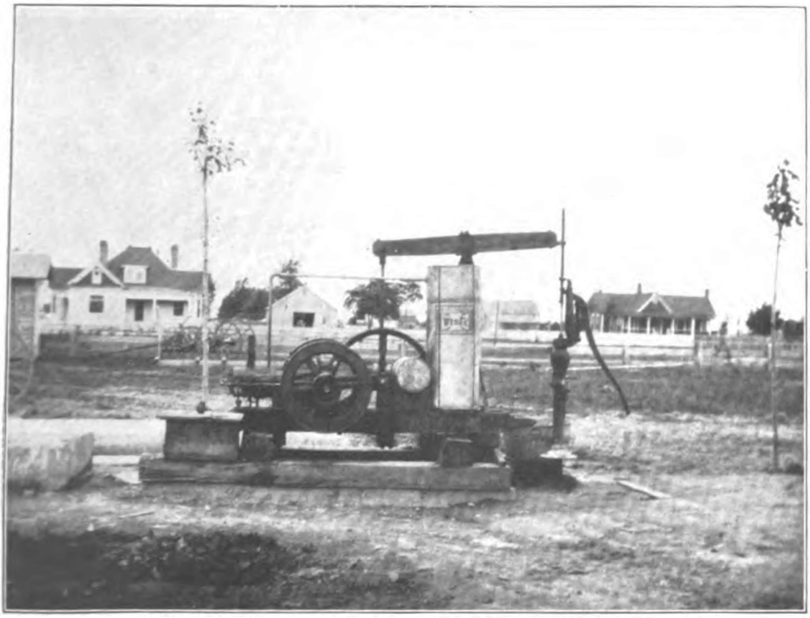
GROUND-WATER DIVISIONS.

The earth's crust may be divided into three zones, according to the conditions of underground-water circulation: (1) The unsaturated zone, extending from the surface of the ground down to the upper surface of the ground-water body, or the "water table," as it is commonly termed; (2) the zone of shallow or, as they are frequently termed, "surface waters," extending from the level of the water table down to the first impervious stratum of considerable extent; and (3) the zone of deep-seated waters, or those lying below the first impervious stratum. The unsaturated zone may contain a considerable amount of water, but it is not stationary, being simply in transit from the surface downward to the water table, or surface of the zone of shallow waters. The zone of shallow waters as here defined is a unit, but the zone of deep-seated waters is not a unit, as there are in most cases several subdivisions, depending on the presence of impervious strata within the zone.

GROUND-WATER TABLE.

The water table in general shows a somewhat close agreement with the slope of the surface of the land, tending to flatness under plains and to inequalities, similar to those of the surface, in the hilly regions. The undulations of the water table, however, are less marked than those of the land surface, the water standing considerably below the top of the ground at the crests of the hills while it is practically at stream level in the valleys. The depth of the ground water below the surface depends on the rate of lateral percolation into the streams as compared with the rainfall. In the eastern United States the permanent ground-water level is seldom at a great depth below the surface, water being commonly obtained within 30 to 40 feet of the top of the ground in lands of moderate elevation, while in valleys supplies are often obtained at depths of 15 feet or less. In the arid regions, on the other hand, the ground-water level may be many hundred feet below the surface.

[a] Data furnished by M. L. Fuller.



A. GASOLINE PUMP AND METHOD OF ATTACHMENT.

B. APPARATUS FOR PUMPING BY HORSEPOWER.

Photograph by M. L. Fuller.

The relations of the ground-water table to the surface in a region of uneven topography are shown in fig. 2.

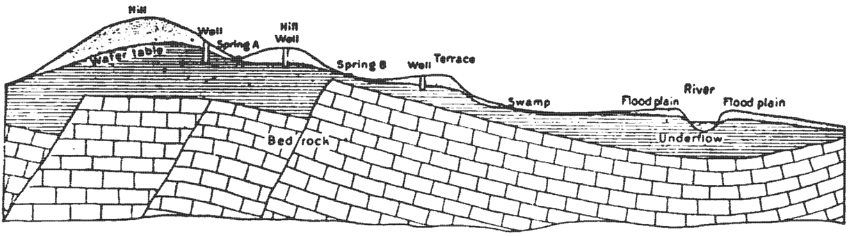


Fig. 2.—Ideal section through valley and hills, showing the position of the ground water and the undulations of the water table with reference to the surface of the ground and to bed rock. (After Slichter.)

RECOVERY OF UNDERGROUND WATERS.

Shallow waters.—The waters of the shallow zone are recovered through springs or seepages and by open or driven wells. The manner in which the former emerge has already been suggested in the paragraph relating to the ground-water table, the water coming to the surface wherever this table is cut by a valley or other depression. This natural process of recovery is supplemented by open wells, which are simply circular excavations dug from the surface to or slightly below the water table. To the use of this form of well there are many objections, some of which are considered on pages 74 and 75. (Pl. VI, *B*, p. 74) A better form of well is the driven type, which is made by forcing a pipe with an open end, or with a perforated point, downward into the ground-water body, by which process the possibility of contamination by the entrance of surface waters is prevented. (Pl. VI, *A*.) In both types of wells the water must be raised by bucket, pump, or other mechanical means. Two methods of pumping water which are in common use are shown in Pl. IV. The use of gasoline pumps promises to be very successful in localities where windmills are not practicable.

Deep-seated waters.—The deep-seated waters generally occur in gently dipping porous beds between more impervious strata. In general the water escapes at the surface only where there is a break in the impervious covering, allowing it to come up along fissures or other crevices. Springs and wells depending on deep-seated waters are more independent of rainfall, show relatively slighter changes of temperature, are more free from contamination, and are more stable in flow than those from the more shallow sources. The deep-seated waters are artificially brought to the surface by means of deep wells. In such wells the water is generally under pressure and rises far above the point at which it is encountered, in some cases reaching to or even considerably above the level of the ground at the well, though in others it may fail to reach the surface, and pumping must be resorted to. In the present paper the term "artesian" is used to designate all wells in which the water is under material hydrostatic pressure and will rise in the well when the impervious capping is penetrated.

ARTESIAN REQUISITES.

The chief artesian requisites are an inclined pervious bed lying between two impervious beds and having its outcrop at a height greater than the surface at the well, an outcrop favorable to absorption, a rainfall sufficient to furnish the necessary supply, and the absence of extensive leakage. Until recently these conditions have, in fact, been regarded by every one as essential, but it has lately been shown that flows can be obtained even in uniform sand. The arrangement of the grains in horizontal laminæ, due to stratification, so opposes the passage of the water that it can rise through the well with much greater ease than through the sand itself. In fact, it seems likely that a difference in the level of the water table in closely adjacent regions sufficient to furnish a working head is the only essential

requisite of an artesian flow.[a] Four of the most common types of artesian conditions are illustrated in the accompanying diagrams (figs. 3, 4, 5, 6).

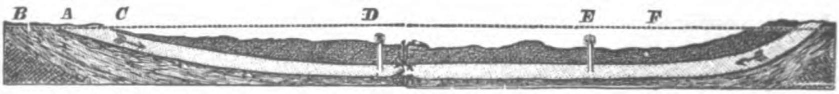


FIG. 3.—Section showing certain conditions governing artesian wells. A, a porous stratum; B, C, impervious beds below and above A, acting as confining strata; F, height of water level in porous bed A, or, in other words, height of reservoir or fountain head; D, E, flowing wells springing from the porous water-filled bed A. (After Chamberlin.)

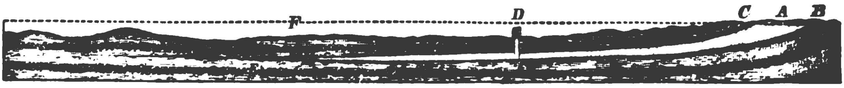


FIG. 4.—Section illustrating thinning out of porous water-bearing bed A, inclosed between impervious beds B, C, thus furnishing conditions for artesian well D. (After Chamberlin.)

FIG. 5.—Section showing transition from porous to impervious bed. A, a close-textured, impervious bed, inclosed between impervious beds B and C, furnishing conditions for an artesian well D. (After Chamberlin.)

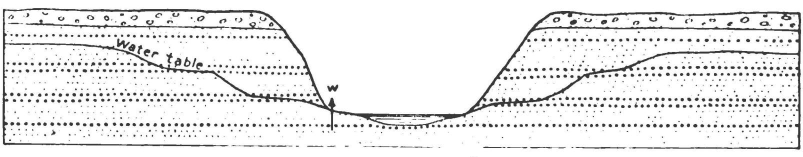


FIG. 6.—Section showing conditions favorable to flows from unconfined sandy strata. (After Fuller.)

SPECIAL CONDITIONS IN COASTAL PLAIN FORMATIONS.

In early treatises on artesian conditions it was argued that flowing wells could be obtained only in low regions with higher land on either side—that is, the artesian well must be located in a synclinal basin. But such is not the condition in the Atlantic and the southern portion of the Gulf Coastal plains.

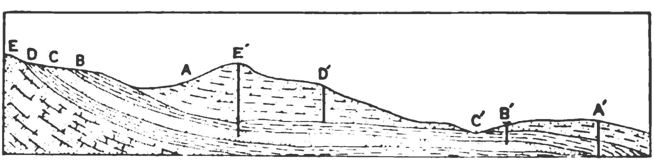


FIG. 7.—Section showing conditions governing artesian and flowing wells in the Costal Plain formations. A, surface sands—clays and sands; B, impervious stratum of clay. C, water-bearing sand; D, impervious stratum of clay; E, Pre-Coastal Plain deposits of limestone and sandstone; A′, D′, E′, common wells; B′, flowing well; C′, spring

The great series of unconsolidated sediments belonging to the Gulf Coastal Plain were deposited upon a sea floor of older rocks sloping gently seaward from their present outcrop along the foothills of the southern Appalachian plateau. The Coastal Plain sediments are thickest at the Gulf coast, where they reach a thickness of more than 2,000 feet. They become thinner and thinner to the north, finally disappearing at the outcrop of the older rocks.

[a] Fuller, M. L., Artesian flows from unconfined sandy strata: Engineering News, vol. 52, pp. 329-330.

The sand and clay sediments of Mississippi were deposited in comparatively shallow water near the old shore. In these deposits the fine supply of artesian and deep-well waters are stored. It frequently happens in this State that the sediments which are water-bearing in one locality change in character in a very short distance and become impervious to water. We shall present only five conditions, which will serve to illustrate the character of the sediments and the possibilities of getting water in the State.

In fig. 7, E represents the older rocks on which the Coastal Plain deposits D, C, B, A were laid down. C is a water-bearing sand incased between two impervious strata, D and B, which prevent the water from leaking out and keep it under hydrostatic pressure. The stratum C cuts out before reaching A′, on the extreme right side of the figure; here there is a water-bearing sand at the surface, but it will not furnish artesian water because of the lack of an upper confining stratum. A′, B′, D′, and E′ are wells. There is no flow at A′ because the artesian bed C fails to reach it. B′ enters the artesian bed C and the water flows above the surface. C′ is a spring. The well at D′ is a strong stream of good water, but does not flow because of lack of depth. The well at E′ enters the artesian sand and the water rises to within a few feet of the surface, but does not flow because the elevation of the mouth of the well is above the head of the water.

UNDERGROUND-WATER HORIZONS OF MISSISSIPPI.

The Gulf embayment includes western Florida and Georgia, southern Alabama, all of Mississippi, western Tennessee and Kentucky, southern Illinois, southeastern Missouri, eastern Arkansas, Louisiana, and southeastern Texas. Within this vast basin there are

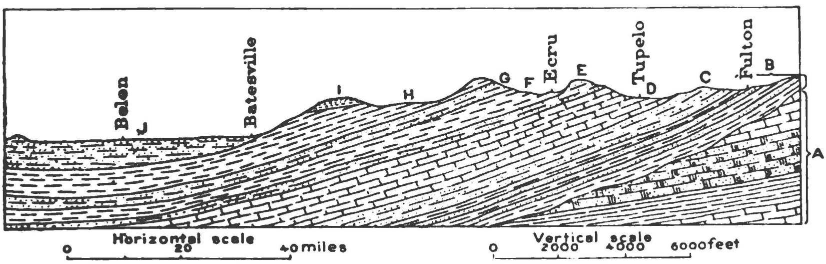


FIG. 8.—Cross section from Alabama to Mississippi River, in latitude of Tupelo. J, Port Hudson; I, loess; H, Wilcox; G, Porters Creek; F, Clayton; E, Ripley; D, Selma; C, Eutaw; B, Tuscaloosa; A, Paleozoic.

several distinct artesian-water horizons. With the exception of a small area of northwestern Alabama the gathering ground of the different water-bearing horizons of Mississippi lies entirely within the State.

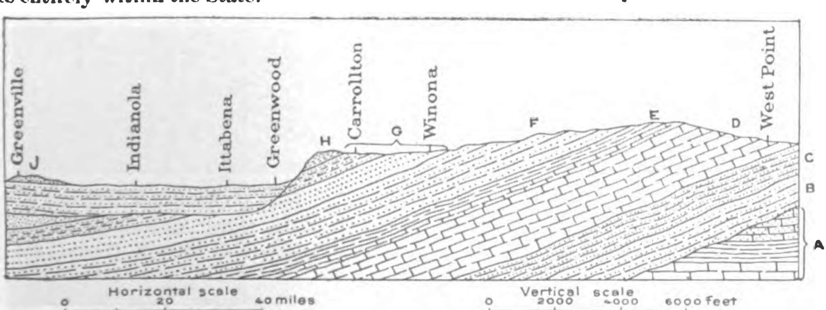


FIG. 9.—Cross section from West Point to Greenville. J, river alluvium; I, Port Hudson; H, loess; G, Tallahatta; F, Wilcox; E, Midway; D, Selma; C, Eutaw; B, Tuscaloosa; A, Paleozoic.

In the cross sections of the State (figs. 8, 9, 10, and 11) an effort has been made to show the relations of water-bearing to nonwater-bearing horizons. These have been prepared from a study of the well records and the surface outcrops of the different geologic formations.

There are seven distinct artesian-water horizons in Mississippi. Beginning with the lowest member of the Cretaceous we shall treat them as follows: (1) Tuscaloosa-Eutaw, (2) Ripley, (3) Wilcox, (4) Claiborne, (5) Pascagoula, (6) Grand Gulf, (7) Lafayette.

TUSCALOOSA-EUTAW HORIZON.

The upper division of the Tuscaloosa and all of the Eutaw formation constitute one artesian-water horizon. The lower division of the Tuscaloosa consists of heavy-bedded, compact clays of various colors. These clays form the lower confining beds of the Tuscaloosa-Eutaw horizon. The "blue rock" of the lower Selma forms the upper confining beds. Between these two water-tight beds are 1,000 to 1,200 feet of cross-bedded sands and gravel, interbedded with more or less irregular strata of sandy clays and occasional beds of lignite.

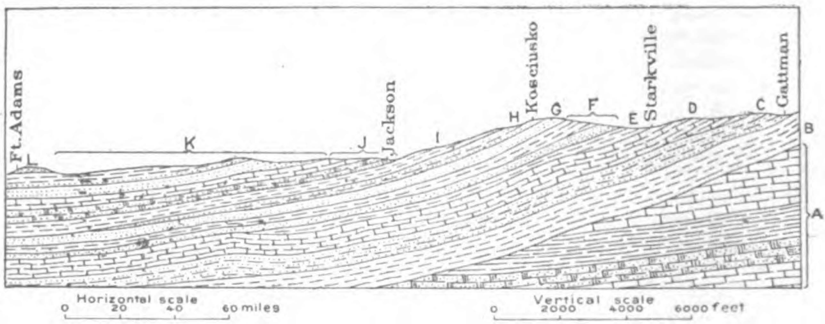


FIG. 10.—Section from Gattman to Fort Adams. L, loess; K, Grand Gulf (sandstone and clay); J, Vicksburg (limestone); I, Jackson (clays and marls); H, Claiborne; G, Tallahatta (sandstone); F, Wilcox (sands and clays); E, Midway (limestone and clays); D, Selma (limestone); C, Eutaw (sands and clays); B, Tuscaloosa (sands and clays); A, Paleozoic (limestone, etc.).

If the numerous beds of clay were continuous throughout the formations they would divide the group into separate water horizons, and no doubt some of the beds do extend over large areas and locally affect the height of the water horizons. Where these formations have been most carefully studied at the surface it has been impossible to trace any definite horizon of sand or clay for a great distance. Along some of the river bluffs, where good exposures are obtained, the material often changes within a hundred feet from a

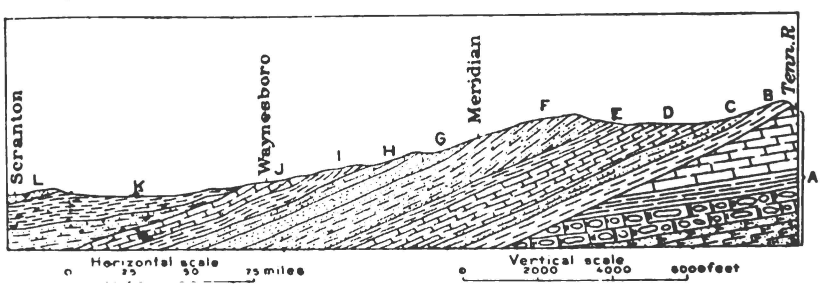
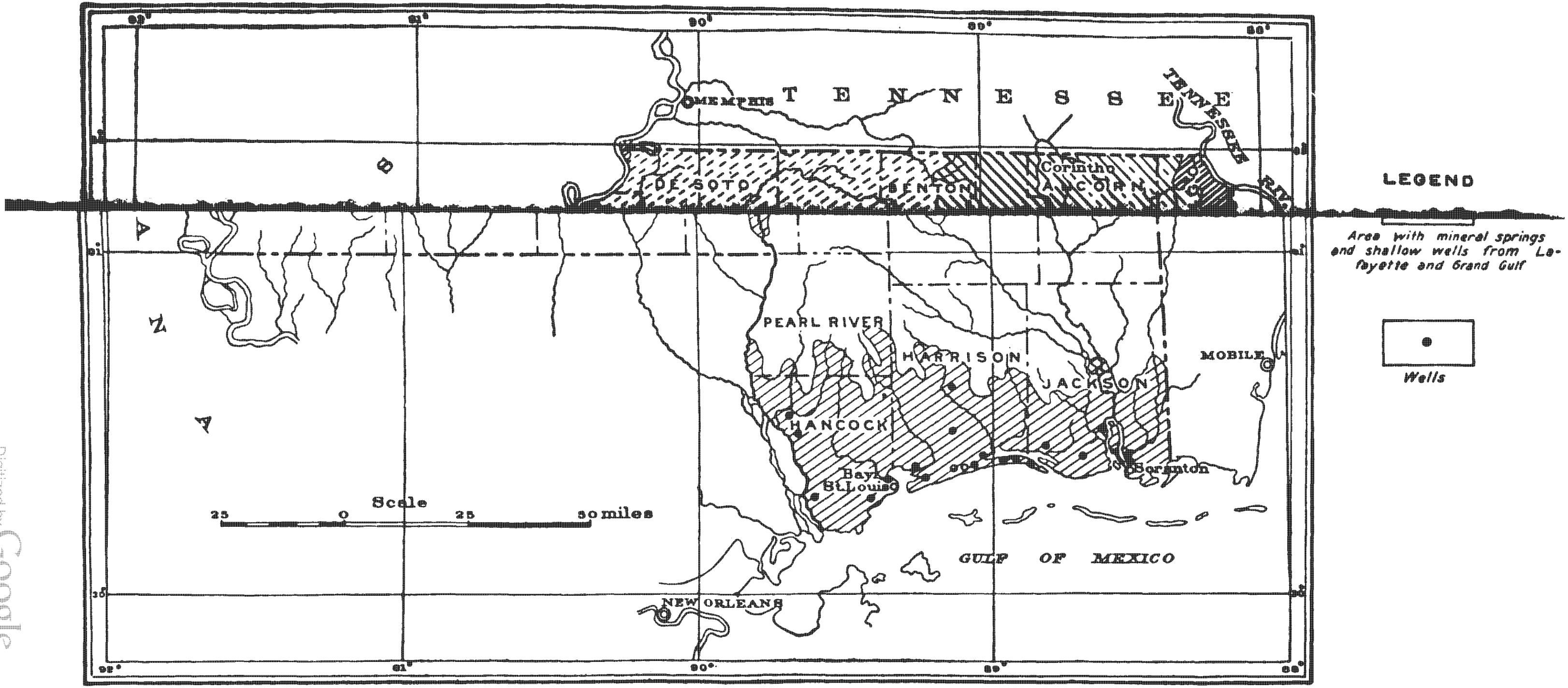


FIG. 11.—North-south cross section from Scranton to Tennessee River. L, Quaternary (silts); K, Grand Gulf; J, Vicksburg; I, Jackson; H, Claiborne; G, Tallahatta; F, Wilcox; E, Sucarnochee; D, Selma; C, Eutaw; B, Tuscaloosa; A, Paleozoic.

laminated clay to cross-bedded sands. Because of the changeable character of these formations we have considered the Tuscaloosa and Eutaw as forming one artesian-water horizon.

Catchment area.—The outcrop of the sands receiving waters of the Tuscaloosa-Eutaw horizon covers about 2,000 square miles, including practically all of Tishomingo and Itawamba counties, the eastern portions of Alcorn, Prentiss, Monroe, and Lowndes counties,



ARTESIAN-WATER MAP OF MISSISSIPPI.

Miss., and Pickens, Lamar, and portions of Marion and Franklin counties, Ala. The region where the water-bearing sands come to the surface is largely in the hilly districts east of Tombigbee River. In the southern portion of the catchment area the elevation is sufficiently high to force the water to the surface over a large area lying to the west. The catchment area from southern Tishomingo County to Tennessee is but little above the territory lying west and the result is that it is impossible to get strong flowing wells north of Baldwyn. However, plenty of good water is obtained near the surface and there are flowing wells along the lower streams to the east.

Upper confining stratum.—In an artesian basin it is necessary to have at least a confining stratum of relatively impervious material above the water-bearing sands. If there is not a confining bed below these sands the water will fill them and the underlying porous rock until a point is reached where the rocks are nonporous.

The overlying Selma chalk contains in its lower part a large amount of compact clay, which forms an impervious layer and prevents the water in the Tuscaloosa-Eutaw from escaping upward. There are areas, however, in the western region of the Eutaw where it is possible to get artesian wells. In these areas there is in the upper part of the Eutaw formation a bed of clay which is sufficiently thick to confine the water below. Farther west the water is under greater pressure and the Eutaw clay bed perhaps loses its compact character, so that the water rises to the base of the Selma chalk and overflows the surface wherever the Selma is penetrated.

Inclination of the beds.—The dip of the strata in the Tuscaloosa-Eutaw horizon varies from a westward dip of about 15 feet to the mile in the north to a south-southwest dip of 35 to 40 feet to the mile in the south. With such a steep dip the water-bearing sands soon pass beneath the overlying strata, and the greater the distance from the outcrop the more difficult and expensive it becomes to reach the artesian waters.

Area of available artesian water.—The westernmost location getting its water from the Tuscaloosa-Eutaw horizon is Starkville. The deepest well here is 1,000 feet, and the water rises to within 154 feet of the surface. Starkville is near the west outcrop of the Selma formation, in which it is impossible to get good water; but fortunately, it can be obtained over the entire area by drilling through the Selma into the Tuscaloosa-Eutaw. It must not be expected, however, that flowing wells can be obtained over the entire area. They are limited to the eastern half of the Selma prairie, extending from about the northern boundary of Lee County south to Noxubee County.

There are often erroneous ideas among well drillers and those unacquainted with the laws governing underground waters. One of the commonest is that, by going deep enough, flowing wells can be obtained anywhere. The Tuscaloosa-Eutaw is the lowest known water horizon in Mississippi, and it would be impossible to get flowing wells from this horizon west of the Selma prairie region. There are no doubt places west of the prairie region where the surface is lower than the head of this water horizon. The question may be asked, "Why can not flowing wells be obtained west of the Selma under such conditions?" But allowance must be made in this, as in all other horizons in the State, for the friction the water encounters in passing through the porous medium. The possibility of getting flowing wells decreases as the distance from the head increases. Another obstacle is the great depth of the water below the surface. If the surface dip of 30 feet to the mile continues to the west, at a distance of 100 miles from the head of the water it would require a well 3,000 feet deep to reach the water horizon.

RIPLEY HORIZON.

In going westward from the Tuscaloosa-Eutaw outcrop, or upward in the geologic column, the next art[illegible] horizon encountered is a small area receiving its water from the [illegible] entire area of this formation occupies approximately 600 square miles, including a small portion of Chickasaw, Pontotoc, Union, Tippah, and Alcorn counties. It includes a long triangular belt having a maximum width of 18 miles in Tippah County and forming an apex near Houston.

Catchment area.—The water of the Ripley occurs in the lower portion of the formation, which is made up of alternating strata of limestone, marl, and sand. The water-bearing strata come to the surface in the hills near the eastern border of the Ripley outcrop—that is, along the western slope of the Pontotoc divide. The country slopes westward and is drained by Tallahatchie River and its tributaries.

Upper confining stratum.—The alternating beds of sandstone, clay, and limestone of the Ripley are overlain by the heavy-bedded, compact clay of the Porters Creek formation. This clay is impervious, and confines the water in the Ripley.

Dip of the water-bearing stratum.—No accurate measurements have been made of the dip of the Ripley sands. There is but one line of wells which get their supply of water from the Ripley, and these wells are about parallel to the strike of the strata. Farther west the Wilcox has been found to have a westward dip of about 16 feet per mile, and the Selma chalk to the east has a westward dip of 10 to 15 feet per mile, so that we can assume that the inclination of the Ripley is about 12 to 15 feet per mile.

Area of available artesian water.—Flowing wells have been obtained from the Ripley horizon only along upper Tallahatchie River and some of its upper tributaries. A large number of wells have been drilled in the vicinity of New Albany and Ecru. When the first ones were drilled at New Albany, the water rose 20 to 30 feet above the surface, but the increasing number of wells soon lowered the head, and they now have to be pumped.

The writer observed for six hours the pumping of a new well at Ecru. The depth was 93 feet, and the water, when the well was completed, barely rose to the surface, as it does in the other wells in the town. After six hours' pumping with a Cook pump drawing 120 to 130 gallons a minute, the other wells in town were lowered 3 feet. This indicates that they all derive their water from the same source and that the supply is limited.

Efforts have been made to get flowing wells at Pontotoc and other places south to Houston, also at places north of New Albany, but without success. The reason is not far to seek. The elevations of Ecru and New Albany are 374 and 381 feet, respectively. At these places the water barely reaches the surface, which indicates that the head is but little above these elevations. From Cherry Creek to Pontotoc the elevation rises from 375 to 478 feet. Pontotoc is located on the crest of Pontotoc divide, and there is no higher land to the east to supply artesian water; it is therefore impossible to get flowing wells at that place From New Albany to Ripley the elevation rises from 381 to 525 feet, thus getting above the water head to the east. The only place where flowing wells from this horizon can be expected is down Tallahatchie River, and perhaps along the headwaters of Tippah Creek in western Tippah and eastern Benton counties, and in northeastern Calhoun County along Shooner River.

WILCOX HORIZON.

The extensive outcrop of the Wilcox formation covers 8,000 square miles, including approximately the counties of Benton, Lafayette, Yalobusha, Calhoun, Webster, Choctaw, and Winston, and the larger portions of Kemper and Lauderdale counties. Only the lower division of the formation is included in the water-bearing horizon.

Catchment area.—The porous sands and sandy clays which come to the surface in the eastern half of the area and lie between the water-tight beds of the Porters Creek and the belt of clays used for stoneware at Holly Springs and Oxford make up the Wilcox artesian-water horizon. The catchment area is largely covered by the Lafayette sands, which offer but little obstruction to the absorption of the rainfall, and a large amount sinks quickly into the underlying strata.

Upper confining stratum.—The stoneware clays of Holly Springs and Oxford, which form a narrow belt of country about the middle of the formation, extending from the Tennessee line south in a semicircular direction into Alabama, form the upper confining stratum of this horizon. These clays change from a white or gray color in the north to a chocolate-brown in the central and southern areas.

Dip of the water-bearing strata.—An east-west line of wells extending from Oxford to Belen gives the following data for determining the dip of the strata, if it is assumed that the water comes from the same source:

The elevation of the well at Oxford is about 450 feet. Water was obtained here at a depth of 100 feet, or 350 feet above sea level. In the Batesville well, water was struck at 285 feet, or 51 feet above sea level. This gives a difference of 401 feet in the elevations of the water horizon. The distance between Oxford and Batesville is 24 miles. By dividing 401 by 25 we obtain the dip of the strata, which is over 16 feet to the mile. Similar calculations between Batesville and Belen give a dip of 17 feet to the mile, and between Batesville and Riverside a dip of 18 feet to the mile. We can therefore assume a westward dip in this region of 16 or 17 feet to the mile.

There are but few data for determining the dip to the south in the southern part of the formation. However, we know from the underlying and overlying strata that the dip is much greater to the south than to the west.

Area of available artesian water.—The area underlain by the Wilcox sands and sandy clays includes the entire State west and south of their outcrop; but the inclination of the beds soon carries the water-bearing strata below the reach of the drillers. Two causes tend to make flowing wells more easily obtained west of the source than south: (1) The more gentle westward dip keeps the water nearer the surface, while the dip to the south soon carries the water horizon beyond reach; (2) the elevation of the surface lying west decreases and reaches a lower level than that to the south.

The flowing wells in the Yazoo Delta north of Leflore County obtain their water from the Wilcox. South of this area water is found in a different horizon. In the western and southern portions of the delta the distance from the source has become so great that the water fails to reach the surface on account of the friction it encounters in passing through the sands. There is but a small area outside of the northern part of the delta where flowing wells are obtained from the Wilcox horizon. Those at Water Valley and Coffeeville, many in Lauderdale, and a few in southeastern Newton, and perhaps in northern Clarke County, get their waters from the Wilcox.

CLAIBORNE HORIZON.

We have considered the white and chocolate-colored stoneware clays near the middle of the Wilcox formation as the division between the Wilcox and Claiborne water horizons. They form the upper confining beds of the Wilcox and the lower confining beds of the Claiborne. If there were a water-tight bed at the top of the Wilcox, there would be two water horizons belonging entirely to this formation; but, since this upper impervious bed is wanting, we should consider the sands and sandy clays above the stoneware clays as a part of the Claiborne formation.

Catchment area.—Besides the area of the upper Wilcox the catchment area of the Claiborne includes a belt from 12 to 40 miles wide extending from Grenada County south-southeast through Carroll, Attala, Leake, southwestern Neshoba, Newton, Lauderdale, and Clarke counties. The belt is narrowest near the Alabama line and widest in Leake County. The outcrop of the strata of the Claiborne horizon includes beds of unconsolidated micaceous sands, sandy clays, and more or less coarse-grained micaceous sandstone. There is in the Tallahatta buhrstone at least one horizon of very compact quartzose sandstone. All of the Tallahatta, with the possible exception of the quartzose sandstone, is capable of holding a large amount of water in saturation. Over much of the area the Lafayette covers the surface. Along many of the streams and hillsides the Lafayette has been removed by erosion and the porous sands and sandstones of the underlying formations are exposed. Besides the direct absorption of the rainfall into the porous strata there are a number of streams which lose a large amount of their waters in passing over the inclined edges of these strata. The water sinks quickly into the open-textured sands, and many of the smaller streams flow but a short time after even a hard rainstorm. This is particularly

true along the upper courses, where the streams have not silted up their beds with impervious clays. The absorption is greater in summer than in winter.

Upper confining stratum.—The upper confining stratum of the Claiborne horizon consists of a series of "soapstone" and pipe-clay beds which belong to the basal part of the Lisbon formation. Well drillers say that in places flowing water is found just beneath a very hard "flint" or sandstone, which is perhaps the quartzose sandstone of the upper Tallahatta.

Dip of the water-bearing strata.—The dip of the strata to the west, as shown in the well records between Winona and Indianola, is as follows: If the waters derive their supply from the same source, there is a dip in the water horizon between Winona and Greenwood of 18 feet to the mile, though one well at Greenwood would give a dip of only 10 feet to the mile; the dip between Greenwood and Ittabena is 20 feet to the mile; between Ittabena and Indianola 35 feet to the mile.

The well at Jackson gets its water at a depth of 1,168 feet. The elevation of the top of the well is about 280 feet above sea level. Estimating the head of the water supplying the well to be 100 feet higher than the surface at Jackson and the distance from the source to the well to be 50 miles, we get a dip of the water-bearing sands of 25 feet to the mile.

Various estimates made from records of the wells along Chickasawhay River give a southward dip of the water horizon of from 10 to 20 feet to the mile.

Area of available artesian water.—The area of accessible artesian water coming from the Claiborne horizon includes the larger part of the Yazoo Delta lying south of a line running from Grenada to Rosedale, and the central prairie belt extending from Yazoo to Waynesboro, on Chickasawhay River.

The area of flowing wells occupies a much smaller territory. In the delta it includes Leflore County, the larger part of Sunflower County, and the northern part of Holmes County. West of this the water encounters too much friction to give good flowing wells. A well 1,567 feet deep at Yazoo failed to obtain a strong flow. The city well at Jackson is perhaps the most distant one receiving its water from the Claiborne horizon. This well is 1,168 feet deep and gives a strong stream. The water is highly impregnated with minerals and too warm to be palatable for drinking. There are numerous flowing wells along Chickasawhay River, from Waynesboro to near Decatur, in Newton County; those south of Enterprise receive their waters from the Claiborne horizon.

PASCAGOULA HORIZON.

Immediately underlying the Grand Gulf formation is a series of older Miocene beds which outcrop along Chattahoochee River in Florida and also along Conecuh River in southern Alabama. From fossils collected by Mr. Johnson along Chickasawhay River a few miles above the mouth of Leaf River it has been shown that there is a horizon here bearing a fauna which is much older than the Vicksburg. He has called the beds Pascagoula, and refers them to the Miocene. It has not been conclusively proved that the Pascagoula is the same horizon as the Chattahoochee beds, but the fossils which were collected have been referred to the Miocene. It is quite probable that many of the deeper wells along the coast derive their supply of water from the Pascagoula, but as the formation has been recognized only along the Pascagoula River nothing is definitely known about its water-bearing capacity.

GRAND GULF HORIZON.

But little detailed geologic work has been done over a large part of the Grand Gulf area from Jackson to the Gulf, and the character of the water-bearing horizons is known only in a general way. The southern counties of the State are covered deeply by two great surficial formations, the Grand Gulf and the Lafayette. The great well at Rose farm and another at Wilson Springs, north of Moss Point, demonstrate that there is another important water horizon underneath the Grand Gulf. The greater part of the wells along the coast find flowing water at 500 feet, more or less, and many toward the west at 300 feet and lower. None of these flow with the great pressure of the deeper wells, nor do they furnish so great a supply. From only one of the shallower wells have fossils been obtained—that at Logtown, on Pearl River—but as yet they are undetermined.

Mr. L. Sutter, one of the most skillful and observant drillers of the coast, says that there are four distinct artesian water-bearing strata on the coast. This does not include the one immediately under the alluvial sands at a depth of 100 to 200 feet, which sometimes flows and sometimes does not. One horizon is reached at about 300 feet from which water occasionally rises to the surface; a second at 400 to 500 feet often gives a strong flow, and the majority of owners are content to stop here; a third is at 600 to 700 feet, in which there is generally gravel and a good flow of water; the last flow comes from a depth of 800 to 1,000 feet, and has a strong pressure and abundant supply.

The lowest member of the Grand Gulf formation is a bed of impervious clay about 75 feet thick. Resting on the clay is a series of sandstones alternating with grayish and often lignitiferous clays. These sandstones and open clays form the water-bearing strata of the Grand Gulf.

Catchment area.—The sandstones and lignitiferous clays come to the surface along the northern area of the Grand Gulf formation. In the northwestern portion the sandstone is more prevalent than the lignitiferous clays. It alternates with thin strata of gray clay, as is shown at Star and Raymond, and in various places in southern Rankin, Hinds, Simpson, Copiah, and Claiborne counties. Along the northern outcrop of the Grand Gulf in the eastern part of the State the sandstone is wanting. The strata here are lignitiferous, sandy clays containing leaf impressions and often fragments of lignitized wood. But the material is porous enough to absorb a large amount of water, which is easily recognized by its character when it again comes to the surface. The large amounts of gypsum and common and magnesian salts, the small quantities of iron pyrite, and the decayed vegetable matter render the water in places unsuitable for drinking.

Upper confining stratum.—The upper confining beds of the Grand Gulf horizon consist of the extensive clay beds outcropping in the vicinity of Hattiesburg.

Dip of the water-bearing strata.—If the wells at Laurel and Ellisville derive their supply from the same horizon, the southward dip of the strata is about 11 feet to the mile. The dip between Ellisville and Hattiesburg is, according to the data in hand, much less. We have but one well record at Ellisville on which to base our estimates, which are no doubt too small.

Area of available artesian water.—The sandstones and porous clays forming the catchment area of the Grand Gulf horizon soon pass beneath younger deposits. Flowing wells are obtained at Taylorsville, Hattiesburg, Columbia, and along the coast. There is a large area lying north of a line drawn from Leakesville through Hattiesburg, Monticello, Brookhaven, and Natchez, where deep-well water can be obtained at a maximum depth of 800 feet. Flowing wells should be found along the larger streams at a much shallower depth.

Below is a generalized section of wells between Biloxi and Pass Christian. The record was given to G. D. Harris, for his "Underground Waters of Southern Louisiana," by Mr. A. Dixon, a practical well driller of that region.

Generalized section of wells between Biloxi and Pass Christian.

	Depth in feet.
6. Sand	80
5. Clay	125
4. Sand and clay	425
3. Light-gray fine sand	500
2. Clay	600
1. Water-bearing sand	685

It will be seen by consulting the section that No. 2 is a bed of clay extending in depth from 600 to 685 feet, with a water-bearing sand below. No. 1 is no doubt the water-bearing sand belonging to the lower horizon, and the clay of No. 2 is the impervious bed at the top. Some drillers say that the clay coming immediately above the water horizon has a bluish-green color and is often 150 feet thick.

The large number of wells along the coast which draw their supply from this horizon indicates a large catchment area. Those who have flowing wells usually let them flow

at full pressure, the amount of water used being but a small fraction of the amount wasted. Well owners should bear in mind the possibility of overdrawing the supply. New wells are being constantly drilled, and this also tends to lessen the amount for each well. Good water such as that found in the deep wells along the coast is a great blessing to the people living there, and a cessation of the flowing wells would be keenly felt. Fortunately, the supply so far has been adequate for all purposes.

LAFAYETTE HORIZON.

The most recent formation in the State furnishing artesian water is the Lafayette. Over the larger portion of the State it forms a mantle up to 200 feet in thickness resting unconformably upon the older formations. The Lafayette passes beneath still younger strata at a distance of 15 to 30 miles from the Gulf and is found in the coast wells at a depth of 150 to 350 feet below tide. North of the point where the Lafayette passes under cover of the other formations, it forms one of the principal sources of the shallow-well waters of the State.

Catchment area.—Along the Gulf and Ship Island Railroad south of Hattiesburg there are thick beds of coarse sand and fine gravel belonging to the Lafayette. They overlie the bluish-green clays at the top of the Grand Gulf horizon, and are in turn overlain by more recent clays. The surface between these two clay layers forms the catchment area of the Lafayette. It is less extensive than the Grand Gulf horizon, but the material is much more porous and therefore contains more water to the cubic foot.

The elevation of the catchment area is sufficient to force the water to a maximum height of 20 feet above the surface. At a distance of 25 miles from the Gulf the elevation along the Gulf and Ship Island Railroad reaches 250 feet. If this elevation were continuous across the State from east to west, the water in the coast wells receiving their supply from this horizon would rise to a much greater height than it does; but the streams have cut their channels to such a depth that the head of the water is much below this elevation.

Upper confining stratum.—The recent clays along the coast rest unconformably upon the Lafayette horizon, and form its upper impervious stratum. From the various reports of the drillers the coast wells from Scranton to Pearl River strike the Lafayette sands and gravel at from 150 to 380 feet. The upper confining bed of clay is reported to be 35 to 100 feet thick. The following table, compiled from the well records from Scranton to Pearl River, gives some interesting facts relating to the pressure and depth of the wells:

Wells between Scranton and Pearl River.

Locality.	Wells less than 500 feet deep.	Wells with flow less than 30 feet above surface.	Wells more than 500 feet deep.	Wells with flow 30 feet and more above the surface.
Biloxi	7	5	15	17
Gulfport		2	6	4
Longbeach		1	2	1
Mississippi City		3	6	3
Pass Christian	2	7	30	25
Fontainebleau			2	2
Moss Point		2	3	1
Ocean Springs		5	13	8
Scranton			2	2
Bay St. Louis	9	8	4	5
Waveland	7	7		

By comparing the depths with the pressures in the table above, it will be seen that the water coming from a depth less than 500 feet has a different source from that of the water coming from a greater depth. Wells with an approximate depth of 500 feet or more

have a much greater pressure than shallower wells. In most of the former the pressure is sufficient to force the water 30 feet or more above the surface, the maximum height being 80 feet. A well at Bay St. Louis, 250 feet deep, has a greater pressure than any of the other shallow wells, and the height of flow above the surface is 20 feet.

Dip of the water-bearing strata.—By comparing the distance from the outcrop of certain beds with the depth at which they are found in the coast wells, a southward dip of about 15 or 20 feet to the mile is estimated.

Area of available artesian water.—The artesian area of the Lafayette is comparatively limited. Some of the more shallow wells along the coast obtain their waters from this horizon. The entire area of the Lafayette which is covered by later formations is but a few square miles, extending about 20 miles north from the coast and including the southern portions of Harrison, Hancock, and Jackson counties.

NOTES ON WELLS OF MISSISSIPPI, BY COUNTIES.[a]

Adams County.—The surface of Adams County is very irregular. In the eastern part the Grand Gulf formation is overlain by the Lafayette. Near Mississippi River the loess overlaps all the other formations and extends from 5 to 10 miles from the river. The wells of this county derive their waters from two sources. The shallower wells are supplied with soft, palatable water from the base of the Lafayette, and the deeper wells from the sands of the Grand Gulf.

The city waterworks company of Natchez has four wells located near together, 56 feet above the river. An examination of the water from No. 1[a] shows 37½ parts solids to 100,000 parts of water, and a hardness of 7½. Well No. 2 contains 27 grains of solids to the gallon, and shows the presence of a very small number of innocuous bacteria. The log of well No. 4 shows 160 feet of loess, 50 feet of Lafayette, and 220 feet of Grand Gulf material. Well No. 9 is located on the Greenville plantation, 7½ miles from town. There are hundreds of wells of this character in the western part of Adams County, the water generally being obtained at the contact of the Lafayette and the underlying Grand Gulf. The log of well No. 9 showed 12 feet of Lafayette and 85 feet of Grand Gulf, to which the water owes its hardness.

Alcorn County.—The Lafayette has been removed from a large part of the surface of the county, which is a gently rolling plateau sloping in a northwest direction to Hatchee River. When the first wells at Corinth were drilled the water rose to the surface, but was lowered several feet below the surface by additional wells. An effort has been made here to get wells which would flow, but the prospects are not very encouraging, since the source of the water is but little above the elevation of the town. There is a bare possibility of striking an artesian flow in the older, hard rocks at a depth of several hundred feet. These rocks come to the surface in northern Alabama and Tennessee at an altitude sufficiently high to force water to the surface at Corinth. However, the disturbance of these older rocks has caused them to be so folded and jointed that it would be a risk to undertake such a project. The log of one of the Corinth waterworks wells, No. 11, shows 20 feet of Lafayette, 280 feet of undifferentiated Cretaceous, and 45 feet of Lower Carboniferous or Devonian.

Amite County.—No well records were obtained from this county. Flowing wells are not probable.

Attala County.—The only well reported from this county is No. 12, at Kosciusko. In this well two fossiliferous beds of clay were penetrated, the first at a depth of 65 feet and the second at 150 feet. Water first entered the well at a depth of 76 feet and now stands at that level.

Benton County.—All shallow-well water in Benton County is obtained from the Lafayette and Wilcox formations. There is a possibility of getting flowing wells from the Ripley sands along Tippah Creek in the eastern part of the county at a depth of about 400 feet.

[a] A partial list of the deep wells in Mississippi is given in the table on pages 40-59. The well numbers in the text refer to this table.

Bolivar County.—This is one of the Yazoo Delta counties bordering on Mississippi River. The shallow wells receive abundant water from the Port Hudson formation, but it contains much organic matter and is therefore very unwholesome. These shallow wells are made by placing a cap on the end of a pipe, perforating the lower portion, and driving the pipe into the ground. Water enters the pipe through the perforations and is raised to the surface by a pump.

The deep wells reach the Claiborne horizon, but are so far from the head that the pressure is greatly lessened by the friction the water encounters in passing through the sands. In most of the counties of the Yazoo Delta bordering the Mississippi the water fails to rise to the surface.

Calhoun County.—This county is traversed by two large streams flowing west, Yalobusha and Shooner rivers. Between these streams is a narrow divide which rises more than 200 feet above them. On the higher ridges and, in fact, everywhere except along the streams the Lafayette is very thick. At its base is a water supply abundant for all ordinary domestic uses. Wherever possible, this water should be used in preference to the deeper well waters, which in this region are apt to be strongly impregnated with mineral salts.

Carroll County.—Carroll is one of the counties bordering the eastern rim of the Yazoo Delta. Its western part is therefore but little above Yazoo River, and flowing wells are easily obtained. The greater part of the county is in the Claiborne hills, where flowing wells are possible only along the lower streams.

The town of Carrollton, near the center of the county, has a large number of flowing wells. It is situated on Big Sandy Creek and has an elevation of 229 feet above sea level. Well No. 17 was drilled 1,250 feet deep, but failed to get an overflow. The first water from the upper Claiborne, at 300 feet, rose to within 17 feet of the surface. A second stream at 450 feet came within 12 feet of the surface. These water beds were cased off and no further supply was obtained. Water from well No. 18 is delivered by a ram to a tank, from which it is distributed over south Carrollton.

Chickasaw County.—The eastern half of this county is underlain by the Selma chalk and the western half by the Porters Creek and Wilcox beds. The water from the Tuscaloosa-Eutaw horizon will rise to the surface in a narrow strip in the northeast corner of the county. Some surficial waters are obtained from the base of the Lafayette where that formation is present, but the general supply of wholesome water comes from the deep wells which reach the Tuscaloosa-Eutaw horizon. Water from well No. 20 at Okolona is forced into a tank by compressed air and is thence distributed over the town.

Choctaw County.—It is not surprising that no artesian wells are reported from Choctaw County, as the high Pontotoc divide extends through its eastern part. At Blantons Gap, 2 miles east of Ackerman, the Illinois Central Railroad reaches the highest elevation between Durant and Aberdeen.

The only possibility of getting flowing wells in the county would be along Big Black River, on the northern and northwestern boundary. Good surficial water is obtainable from the base of the Lafayette, which is exceptionally thick over this region.

Claiborne County.—Good water is obtained in shallow Lafayette and Grand Gulf wells, but there is no artesian flow.

Clarke County.—Clarke County is one of the Alabama-Mississippi border counties lying along Chickasawhay River. The nearness to the catchment areas of the Claiborne and Wilcox formations and the large area of low-lying territory along the Chickasawhay cause many artesian wells. The county is crossed by the Lisbon beds, the Tallahatta buhrstone, and the Jackson formation, while the upper Wilcox crosses the northeast corner, and the Vicksburg the southwest corner. The Lafayette is also very thick back from the larger streams.

Well No. 22, at Barnett, was started in the Jackson marls, which were 65 feet thick. Water was obtained in the sands immediately underlying, and again in sands at 125 feet. At a depth of 350 feet all the water left the well and passed off through the sands at that point. The well was cased for 150 feet. In well No. 23, also at Barnett, water was obtained

at 65 feet and rose 25 feet in the well. At 125 feet another stream was struck which rose to within 20 feet of the surface. As in well No. 22, all the water was lost in the sands at a depth of 350 feet. None was found below that level.

Well No. 24, at De Soto, begins near the top and ends near the bottom of the Lisbon beds. The water has a reddish color like other water coming from this horizon.

The town of Enterprise has two wells (No. 25) about 100 yards apart and of the about same depth. They are affected by a large well drilled at a sawmill a few hundred yards north. The log from well No. 26 showed 22 feet of Lafayette. When first drilled this well had a weak flow. Three other similar wells, from 175 to 200 feet in depth, are located in the neighborhood. Well No. 29 is on the west side of the river and on higher ground than those above mentioned. The Lafayette is here very thin and is underlain by a 10-foot Claiborne shell bed. When the mercurial barometer is high the well flows, but usually it has to be pumped.

About 15 wells have been bored in the town of Quitman. The log of well No. 31 showed 40 feet of Lafayette, 40 feet of Lisbon, 150 feet of Tallahatta buhrstone, and 2 feet of Wilcox. The volume of water has been lessened by the large number of wells. Some of the larger wells used for supplying water for the Mississippi Lumber Company are pumped by compressed air. During the pumping the flow of other wells in the town is either decreased or stopped. Well No. 33 was the first one drilled in Quitman. The flow has been much reduced by the drilling of other wells. The Lafayette in this well was 30 feet thick. To the east in the hills the Lafayette is from 40 to 100 feet thick.

Well No. 34 is the public well at Shubuta. A weak overflow of clear water was obtained at a depth of 175 feet, but the main flow is from 400 feet and is a red water, which is alkaline in character and carries 62 grains of sodium bicarbonate to the gallon. Sixteen flowing wells and 1 nonflowing are reported from the town of Shubuta, and they range in depth from 165 to 422 feet. The maximum height to which the water rises above the surface is 30 feet. There are two distinct water horizons in the Shubuta wells, both of which yield highly alkaline waters. The first horizon, at 165 to 175 feet, yields a clear alkaline water with a pressure sufficient to raise it to a maximum height of 15 feet above the surface. The second horizon, at about 400 feet, yields a red alkaline water which is typical of all waters coming from the uppermost Lisbon beds. The pressure from this level raises the water 20 to 30 feet above the surface. Well No. 43 is 1 mile east of town, on low ground near the river. Well No. 45 is 2½ miles north of town.

Clay County.—The whole surface of Clay County is underlain by the Selma chalk, except a narrow strip 2 to 5 miles wide along Tombigbee River on the eastern border. Over the entire country the water from the Tuscaloosa-Eutaw horizon will rise in wells to within a few feet of the surface. In some localities in the eastern part the water flows over the surface.

The drill in well No. 52 at West Point penetrated more than 500 feet of the Selma, beneath which an unusually pure water was obtained. This well has a weak but steady flow. Later wells, however, have lowered the height of the water.

Coahoma County.—The artesian wells from this part of the Yazoo Delta get their flow from 700 to 1,000 feet below the surface. There is a marked difference in the pressure and quantity of water in some of the wells.

At the town of Clarksdale the city well (No. 53a), which is 876 feet deep, flows a very weak stream of 3 gallons per minute. The well at Lyon (No. 55), only 2 miles north, is 975 feet deep and flows a strong stream of 22 gallons per minute. This well, however, obtains its water from the 970-foot level, which is 94 feet lower than the Clarksdale well. No doubt the latter would strike the same water at the depth of the Lyon well. An analysis of the water from well No. 55 shows 3774.6 parts per million of solids, of which 2738.9 parts are sodium carbonate.

Copiah County.—This county is in the region of the Grand Gulf formation, which is in places deeply covered by the Lafayette sand and gravel. A high ridge extends north and south across the county, separating the waters of the Pearl on the east from those of the Mississippi on the west.

Water was obtained in well No. 56, at Wesson, at a depth of 120 feet in the lignitic clay of the Grand Gulf. It was so highly impregnated with vegetable matter and alkalies as to be unfit for drinking purposes. It is stated that a boring 1,100 feet deep near Wesson failed to obtain water. The drinking water in this locality is obtained from wells at the base of the Lafayette.

Covington County.—The well waters from Covington County come principally from the lower members of the Grand Gulf. There is more or less mineral matter in the water, often rendering it undesirable as a constant drinking water.

De Soto County.—The log of a well in Hernando shows the following relations: Flint gravel 45 feet, yellow clay 20 feet, brown shale 25 feet, light-brown shale 55 feet, hard shell or hardpan 1 foot, light-gray shale 24 feet, and sand 50 feet.

The well was made in sand, is 10 inches in diameter, and has a capacity of 150 gallons daily. Water is raised by a deep-well pump and stands 20 feet below the surface. The quality is about like that of the Memphis water.

Franklin County.—Shallow wells are obtained in Franklin County from the Lafayette and Grand Gulf. Artesian wells are not possible.

Greene County.—Artesian wells may be obtained along Chickasawhay River, in the eastern part of the county. There are as yet no records of any deep wells in this county, perhaps because of the small population.

Grenada County.—Grenada County is cut from east to west by Yalobusha River. Along the lower course of the river on the eastern edge of the Yazoo Delta there are numerous artesian wells.

The town of Grenada is supplied by deep-well water, which is pumped to a large standpipe on a hill about 1 mile from town and from there distributed over the city through pipes. The hill on which the standpipe is located is about 150 or 175 feet above the city and a strong pressure is thereby obtained.

Hancock County.—Hancock County is the most western county bordering on the Gulf. The drainage is toward the south and southwest. The geologic formations belong to the post-Tertiary period. The region of flowing wells includes a strip along Mississippi Sound 5 to 10 miles wide and likewise the region along the Pearl River bottom on the west side of the county.

Twenty-three wells are reported from this county. The temperature of the deeper wells is reported to be 78°. Notes on some of these wells are given below. The numbers correspond with those in the table (pp. 42–45):

No. 57. This well has no strainer at the bottom and became clogged, its flow diminishing from 50 gallons per minute to nothing. After partly cleaning, a flow of 15 gallons per minute was obtained, but this has now decreased to 8 gallons.

No. 58. This second college well is located 1,000 feet from the first. The original flow was 60 gallons per minute, but the well later became entirely clogged. A flow of 5 gallons is now obtained.

No. 59. Abundant gravel, similar to that on Bayou de Lisle, 10 miles northeastward, was found at 40 feet, while at from 175 to 300 feet univalve and clam shells were found.

No. 60. This is one of the shallowest wells at this point. There are some fluctuations of flow of the shallower wells, thought by drillers to be connected with tidal fluctuations.

No. 61. This is one of the best wells at Bay St. Louis. The water is used in a canning factory. A cypress log was encountered at 90 feet, and many fossil shells at 200 feet.

No. 62. In the winter of 1893-94 this well ceased to flow, but began again in the spring and has continued ever since. The flow fluctuates a little with the tide.

No. 63. Fossil shells were found at 170 feet, but none were preserved.

No. 64. This well is 16 feet above tide level. It flows at high tide, but not at low. During storms which raise the water level the flow is greatly increased.

No. 65. This well does not ordinarily flow, but during storms which raise the water of the Gulf it flows freely.

No. 66. Rotten wood, apparently cypress, was encountered at 100 feet and gravel at 190 feet. Water was found at this point, but the well was continued to the second water-bearing stratum at 420 feet. The gravel resembles that at Bayou de Lisle, 10 miles northeast.

No. 67. A good water horizon was passed through at a considerable distance above the one from which the supply is now obtained.

No. 69. This well is located on Bayou Tally, several miles north of town. Fossil shells were found at 40 feet, but none were preserved.

No. 71. Three sources of water were found—one under the Port Hudson, one under the Lafayette at 160 feet, and one near the top of the Grand Gulf at 225 feet.

No. 73. The elevation of this well, like practically all of those at Waveland, is 16 feet above tide. This is the shallowest well at Waveland, the well stopping at the first water-bearing horizon.

No. 74. Water was obtained at 320 feet, but was supposed to be insufficient, and the well was continued 30 feet into the clay.

No. 75. The stratigraphy shown by the wells in Waveland is similar to that at Bay St. Louis.

No. 76. West of Bay St. Louis.

No. 78. This well was continued into the clay several feet below the water-bearing sand.

Harrison County.—This county offers a diversity of topographic features. The southern part, bordering on Mississippi Sound, is but a few feet above tide. Twenty-five miles from the coast the Gulf and Ship Island Railroad reaches an elevation of 270 feet, while the hills to the west rise perhaps 100 feet higher. At the northern edge of the county the railroad reaches 305 feet elevation. These high hills furnish the outcrop of the geologic formations which supply the high-pressure wells along the coast. The entire coast in the southern part of the county is perforated by wells, some of which will force the water 80 feet above the surface with a flow of 450 gallons per minute.

In well No. 102 fossil shells were found at 340 feet, but none were saved. The well supplies a large sawmill and furnishes water for the village of Delisle.

The wells at Pass Christian (Nos. 122–153) are about 16 feet above tide and all have a strong flow, which increases with depth. The supply of the deeper wells appears to come from fossiliferous beds which Mr. L. C. Johnson has referred to the Pascagoula. The water from the shallower wells comes from one or all of the three water-bearing sands above the so-called Pascagoula. The temperature of wells 700 feet deep is 71°.

Hinds County.—The waters of the eastern part of Hinds County flow to Pearl River and those of the western part to the Big Black. It is difficult to obtain good drinking water in the Jackson and Vicksburg formations, which underlie the surface in the northern part of the county. More than half of the southern part is underlain by the Grand Gulf formation, which is here represented by white to gray sandstone, interbedded with sandy clays and unconsolidated sands. The Lafayette covers the surface of the entire county except in small areas.

The high bluffs along Big Black River are covered with loess, which overlies all the other formations. It gradually thins out to the east, becoming so closely blended with the yellow loam that the two are inseparable. The transition zone will stand erosion better than the unmixed yellow loam. Most of the water in this county is obtained in shallow wells, which derive their supply from the base of the Lafayette.

There are four flowing wells in Jackson. The city well is located on the bank of Pearl River, not far from the wagon bridge. The well is 1,168 feet deep and flows a strong stream of strongly alkaline, warm water. It is so highly charged with minerals that it is not used for any purpose. The source of the water is perhaps the upper Claiborne. The temperature of one of the Jackson wells, 774 feet deep, is reported by Darton to be 74°.

The deepest well (No. 157a) in this section is at Bolton. At a depth of 1,020 feet a fine stream of excellent drinking water was obtained, which rose to within 80 feet of the surface. The well was continued to a depth of 1,517 feet, but no further streams were obtained. At a depth of 1,080 feet the first rocks were found. They occurred in bands 1 to 5 feet thick to the bottom of the well.

Holmes County.—The topography and stratigraphy of Holmes County is very similar to that of Carroll on the north. It contains a high north-south ridge near the center and two low-lying regions on either side. In both of these low areas are numerous artesian wells deriving their waters from the Claiborne horizon.

Water was first obtained in the well at Pickens (No. 159) at 160 feet, but it was of poor quality. An analysis of the water from the Tchula well (No. 160) shows it to be too alkaline for boiler purposes.

Well No. 162 is located in Attala County, 1 mile from West. It is cased down to solid rock of the lower Tallahatta at a depth of 100 feet. The water comes from beneath the hard rock.

Issaquena County.—Issaquena is a small county bordering on Mississippi River in the southern part of the Yazoo Delta. The surface formations are recent river deposits and Port Hudson, both of which furnish plenty of surficial waters of a poor quality. The region is too far removed to get flowing wells.

Itawamba County.—The Tuscaloosa sands furnish a large amount of fine water over the entire county. There are numerous springs in the western part of the county which issue from just above lignite seams and clay beds belonging to the Tuscaloosa. No doubt flowing wells could be obtained along Tombigbee River, but none are reported.

Jackson County.—The eastern and western parts of Jackson County rise to an elevation of about 300 feet. The central part along Pascagoula River is but a few feet above tide. Like the other two coast counties, the southern part of Jackson has a large number of flowing wells. Twenty wells are reported from Jackson County, and the following notes are given in addition to the data in the table (p. 48–51):

No. 163. Fossil shells were found at 640 feet.

No. 164. Fossil shells of the Pascagoula were found at 500 feet. The formation is here probably about 100 feet thick.

No. 166. This well goes 300 feet below the base of the Pascagoula, assuming the latter to have its normal thickness. It does not, however, reach the Jackson or Vicksburg formations. Mr. L. C. Johnson considers that it may end in the Chickasawhay Miocene beds.

No. 167. This well was bored for oil. At 680 feet it passed through a thin bed of gray sandstone, probably at the base of the Grand Gulf. The water at this level was of a brownish color and flowed 50 gallons to the minute, but was cased off. Woody matter was encountered at 720 feet. The well is located 4 miles north of Moss Point.

No. 168. Most of the city is supplied from this well.

No. 171. The water of wells of this depth is better than that from the deeper wells.

No. 177. The horizon of the water bed is fixed by fossils.

No. 178. This well is used for irrigation.

No. 179. This well was begun for oil, but was abandoned because of the sticking of the drill. It still flows considerably, although the main water horizon at 900 feet was cased off. Fossils of the Pascagoula horizon were encountered below 900 feet. Some wood, lignite, and pyrite were also found.

No. 180. It is probable that the water supply is from a sand bed 40 to 50 feet above the Pascagoula marl.

No. 182. Fossil shells of the Pascagoula formation were found below 600 feet.

Jasper County.—There are 10 wells reported from the town of Paulding, with an average depth of about 80 feet. The water rises only 10 feet in the wells. At a depth of 90 feet the Jackson marls are reached. Water coming from the base of the Lafayette is reported to be good and soft, while wells bored into the Jackson have hard water. The wells are bored with a hand auger.

Jefferson County.—No wells reported.

Jones County.—The Grand Gulf clays underlie the entire county. The more sandy clays are water-bearing, but the southward slope of the land is so gentle that the water does not rise to the surface except in the southern portion of the county. It rises to within 40 feet of the surface at Laurel (No. 184) and to 20 feet at Ellisville, which is 7½ miles farther south. If the dip of the water horizon is constant, the water should rise to the surface in wells 8 miles south of Ellisville, provided, of course, the elevation is no higher than at Ellisville.

Well No. 186, at Laurel, obtained its first water at 65 feet, and water was found at various levels until the large supply was reached at 370 feet. The well is cased for 250 feet, the lower 20 feet being brass screen.

Water has been obtained at Ellisville at 70 feet, clearly within the Grand Gulf; and again at 500 feet, possibly at the base of the Grand Gulf, but this is not certain. In neither case did the head force the water to the surface.

Kemper County.—In the eastern part of the county deep-well water, perhaps flowing, can be obtained from the Tuscaloosa-Eutaw horizon by penetrating the Selma chalk. In the western part numerous shallow wells are obtained at the base of the Lafayette. In some places, where the Lafayette has been cut through, bold springs of pure, soft water are found.

Lafayette County.—This county occupies the central portion of the Wilcox area. In general there is a thin layer of Lafayette overlain by a thicker mantle of the Columbia loam,

which reaches a maximum thickness of 20 feet. In the eastern and particularly in the southeastern part of the county are numerous outcrops of lignite veins along the streams.

The county is traversed from east to west by two large rivers, the Yocona on the south and the Tallahatchie on the north. The principal water supply is obtained from the heavy-bedded sands in the Wilcox.

Lamar County.—This has recently been formed from Marion County, and the wells are discussed under that head.

Lauderdale County.—The high line of hills forming the divide between the Tombigbee and Chickasawhay basins extends in a southeast-northwest direction across the central part of the county. The Wilcox and Claiborne strata, outcropping to the south and west, form the catchment area for the artesian wells in the southern portion of Lauderdale and Clarke counties.

From well No. 190, at Lauderdale, 35,000 gallons were pumped in a five-hour test. There is some iron in the water, but it can be used in boilers. The drill passed through solid beds at about 70 feet below the surface, presumably Wilcox. In No. 192 water was first obtained at 135 feet, but it was from a bed of lignite and was of poor quality. The well stopped in a soft, yielding clay which caved badly. The water from well No. 194, coming from the Wilcox, is very hard, but is used in locomotives. The well has yielded 7,000 gallons per hour.

Well No. 196, at Meehan Junction, passes through the Tallahatta buhrstone and into the Wilcox sands. Only 60 feet of casing are used.

Well No. 197 was the second well bored in Meridian. The flow is said to be abundant, but the amount has never been measured. It is located near Okatibbee Creek, 6½ miles northwest of the courthouse and on much lower ground. Well No. 199 is the public well in one of the streets. A hydraulic motor pumps a small stream from this well, in which the water is chalybeate. The water from well No. 201 is a mineral water, but is distilled for making ice. The flow is ample for the purpose, some of the water being used for drinking supplies.

Wells Nos. 202 and 203, at Siding, obtain their supply from the buhrstone. The flow is greatly increased by drilling about 20 feet deeper than the buhrstone and putting in a longer strainer, as other wells in the vicinity also show.

Lawrence County.—The only formations outcropping in Lawrence County are the Grand Gulf clays and the overlying Lafayette. Pearl River crosses the entire county from north to south.

The water supply comes from both the Lafayette and the Grand Gulf, but the greater number of wells get their supply from the latter at a depth of 50 to 75 feet. The Grand Gulf water here, as at many other places, is hard, but is considered wholesome. No flowing wells are reported from this county.

Leake County.—Two shallow wells from the Lafayette are reported from Leake County. The Tallahatta buhrstone outcrops in the eastern part and furnishes a large amount of good water, but the supply has not been developed. Flowing wells are possible along Pearl River at moderate depths, particularly west of Carthage.

Lee County.—The Selma chalk forms the surface rock over the western and the Eutaw over the eastern part of the county. The slope of the surface is southeast, or about parallel to the strike of the strata. The artesian waters at Tupelo, Verona, Plantersville, and other places over the county come from the Eutaw sands, which outcrop in the hills to the east.

The first wells at Tupelo were drilled in the town and had a strong flow. Later, however, numerous wells along the near-by creek and at the United States fishery have been drilled at a lower elevation, and the water in the town wells has been lowered below the surface. Water is obtained in the United States fishery at a depth of 325 feet. There are six of these wells, which supply the water for the various fish ponds and for domestic use.

The water coming from the Eutaw contains more or less iron oxide, and where the Selma chalk is not cased off the water is high in lime carbonate. Where the wells are cased to the bottom the water is normally soft and wholesome.

Well No. 210 is near the eastern edge of the Selma chalk. The first water obtained at 125 feet rose to within 10 feet of the surface. The next horizon was at 250 feet and the water rose to within 3 inches of the surface. The last water was at 322 feet and flowed weakly.

Leflore County.—Leflore County borders the eastern edge of the Yazoo delta about halfway between Vicksburg and the Tennessee line. The highest altitude does not exceed 175 feet. In the adjacent county to the east the hills rise to a maximum height of 550 feet. The sands furnishing the strongly flowing wells in Leflore County come to the surface in the Carroll County hills and in those farther east. The conditions are thus very favorable for obtaining a large supply of flowing water. Leflore is one of the counties of the delta where the well drillers will guarantee a flowing well.

In well No. 217, at Greenwood, the first water was obtained at 340 feet, the next at 450, and a third at 600 feet, all of which are utilized by means of perforations in the pipe at the proper points. Hard rock, belonging perhaps to the Tallahatta buhrstone, was reported at a depth of 200 feet.

The following generalized section of the wells in and near Minter City was given by Mr. Feigler, a sucessful driller of this region: Subsoil 10 feet, sand and silt 100 feet, gravel 5 to 60 feet, sand 80 feet, soapstone and pipe clay interbedded with sand to the bottom of the wells, which range from 420 to 690 feet in depth. The quality of the artesian water from this county is considered excellent by those using it.

Below is a generalized section of the wells at Greenwood which receive their water from the Claiborne: Brown clay 20 feet, common sand 130 feet, coarse gravel 130 to 150 feet, gray sand 130 to 160 feet, fine "sea sand" 160 to 190 feet, gray sand 190 to 220 feet, soapstone or clay 220 to 300 feet, sand 300 to 380 feet, dark-brown hardpan 380 to 460 feet, and sand rock for about 20 feet, below which is a stratum of flint rock always about 8 inches thick. Water is found below this rock in dark-green sand.

Lincoln County.—This county, like Copiah, its northern neighbor, contains the elevated watershed between Pearl and Mississippi rivers, extending in a north-south direction near the center of the county. The uppermost bed of the Grand Gulf formation is here an impervious clay which checks the water collecting in the Lafayette and provides a fine supply of a soft, wholesome quality. Wells penetrating the compact clay of the upper Grand Gulf obtain abundant water at various horizons. No flowing wells are reported.

Lowndes County.—Tombigbee River approximately marks the division between the outcrop of the Eutaw sands and the Selma chalk. There are in Lowndes County 140 wells, 15 of which are in the city of Columbus. On the east side of the river they all flow, and on the west side they rise to a convenient pumping height. In the river valley it is necessary to bore only 200 to 300 feet for water. One well at Columbus 400 feet deep is reported to have a temperature of 70°.

Madison County.—Big Black and Pearl rivers form, respectively, the southeast and northwest boundaries of Madison County, and opposite Canton they approach within 16 miles of each other. The divide between the two rivers is quite narrow, with a long slope to the Big Black and a short steeper slope to the Pearl.

A large part of the county lies sufficiently low to have artesian wells. Flowing wells should be obtained anywhere along the Pearl River bottom on the east, and also along the Big Black at a maximum depth of 1,000 feet. At the same maximum depth flowing wells should be obtained anywhere along the Illinois Central Railroad north of Calhoun, with possibly the exception of Davis station, north of Canton.

The fine, wholesome water obtained in the Bolton well at a depth of 1,080 feet can be struck in southwestern Madison County at about 800 feet and less, and in many places it will rise to the surface. At the town of Canton good water was obtained at 460 feet which rose to within 40 feet of the surface. The water in the city waterworks well (No. 226), which is 1,020 feet deep, is called soft, but has a mineral taste and odor. Its temperature is 74°.

Marion County.—Artesian wells are easily obtained in Marion County along the low-lying land adjacent to Pearl River. There are a large number of wells, with an average depth of 425 feet, in and near the town of Columbia. The water is mineralized, containing sulphur, iron, and sodium, but it is considered soft and is used for domestic purposes.

Marshall County.—The high elevation of this county makes it impossible to get flowing wells, except perhaps along Tallahatchie River in the southeast corner. There is, however, an abundant water supply for all ordinary purposes in the Lafayette and the underlying Wilcox sands.

The Wilcox sands here are often unconsolidated and thus form a natural filter for the storm waters. On account of the porosity of the sand and the readiness with which the water sinks into the earth, care should be taken in locating wells in the towns and in places where the surface water is apt to become contaminated. Filtering water is not sufficient to remove from it the typhoid germs.

Monroe County.—The western part of Monroe County is underlain by the Selma chalk, the eastern half by the Tuscaloosa, and a narrow strip along Tombigbee River by the Eutaw. The highest part of the county is in the Tuscaloosa, which is the source of the artesian waters to the west. The water-bearing sands have a west to southwest dip of about 30 to 35 feet to the mile.

A well near Caledonia (No. 233) had a most remarkable flow, the water rising with such force that it was found impracticable to put down any casing. Enough sand and clay was washed out to obstruct Buttahatchie River. The well finally clogged itself and ceased to flow. Two others of like dimensions were bored by the same owner with similar results.

Flowing wells are obtained along the valley of the Tombigbee at a depth of about 300 feet. In the prairie region to the west the water rises to within 60 to 75 feet of the surface but does not flow.

Montgomery County.—The eastern part of Montgomery County marks the eastern border of the Tallahatta buhrstone. The hills, however, are not sufficiently high to get flowing wells over the western part of the county. There is a possibility of getting flowing wells in the southeastern part, along Big Black River.

The water from the deep wells in Winona is unusually pure and valuable for drinking purposes and for use in boilers. The following interesting log of one of these deep wells (No. 235) was kept by Mr. R. A. Allison:

Log of deep well in Winona, Miss.

	Feet.
Soil and clay	25
Orange-colored sand	10
"Blue marl" (?)	40
Lignite	5
Quicksand	15
Black clay	50
Coarse sand and fair supply of water	10
Lignite	10
"Blue marl" (?)	35
Fine sand	15
Clay	10
Quicksand	60
Clay	40
Fine sand, coarse on top	25
Brown clay	35
Coarse, water-bearing sand, with gravels at top	27
Total depth	412

The temperature of the water is 65° F. The 50-foot bed of black clay beginning at a depth of 95 feet below the surface is the heavy bed of black clay at or near the top of the Wilcox. At the town of Grenada, 24 miles north of Winona, the black clay shows in the bank of Yalobusha River. At the top of the high hill 4 miles west of Grenada the hard quartzitic sandstone of the Tallahatta forms the cap rock. The same Tallahatta buhrstone is found in the hills west of Vaiden. The heavy bed of black clay coming at or near the top of the Wilcox can be traced from Winona, Miss., in well sections and outcrops to Memphis, Tenn.

Neshoba County.—No artesian wells have been reported in Neshoba County. Good shallow-well water is obtained in the Lafayette, while water at a greater depth may be had at the base of the Claiborne in the southwestern part of the county.

Newton County.—There are five different geologic formations represented in Newton County. The Wilcox and Tallahatta buhrstone are in the northeastern portion, the Lisbon beds in the center, and the Jackson calcareous clays in the southwest. The Lafayette overlies all these formations.

There are a number of flowing wells in the southeast corner along Chickasawhay River, which obtain their supply from the buhrstone. At the town of Chunkey the wells are cased only to the buhrstone, which in well No. 238 was at 16 feet.

An analysis of the water from well No. 242, at Hickory, shows the principal mineral ingredients to be sodium, calcium, and magnesium bicarbonates, but the water is not decidedly alkaline.

Noxubee County.—The greater part of the surface of Noxubee County is a rolling prairie sloping southeastward to Tombigbee River. Flowing wells are obtained along the valleys of Tombigbee and Oaknoxubee rivers. Over the remaining part of the Selma prairie water will rise to within good pumping distance of the surface. Mr. Ladd, of Macon, who has been in the well business for fifty years, reports that water will in general rise to an altitude of 218 feet above sea level in this region. The dip of the beds is reported to be 25 feet to the mile southwestward.

The water from well No. 249, at Macon, is alkaline and gives trouble in the boilers if used when fresh, but after standing it can generally be used.

There are three wells (No. 250) on the farm of Mr. Dent, 10 miles east of Macon, which average 650 feet in depth, and nearly every plantation has one or more.

Oktibbeha County.—The western border of the Selma prairies is in the central part of this county. The Porters Creek clays and Wilcox formation come to the surface in the western half. The Lafayette covers but a small part, chiefly in the west. The great thickness of the Selma, which is barren of water, makes it difficult to get good water. Artesian water is obtained in the northeast corner at a depth of about 300 feet. At Starkville, 11 miles southwest of Muldrow, water is obtained at a depth of 900 feet, which shows a westward dip of the strata of 33 feet to the mile. The water in the Starkville well (No. 253) rises to within 130 feet of the surface.

Well No. 254, at the Agricultural and Mechanical College, has a 100-foot Cook strainer. The first water was from a 50-foot bed of sand, beneath which is a stratum of clay 10 feet thick, and a layer of sand 35 feet thick. The strainer extends through both water-bearing strata.

Panola County.—The high hills of the Wilcox formation occupy the eastern part of Panola County, and the low-lying Port Hudson sands and clays the western part. The source of the artesian water is the Wilcox sands, which outcrop in the hills east of Oxford. The Port Hudson here, as at all other places in the Yazoo Delta, furnishes a large supply of impure surficial water.

The only flowing wells reported are in the town of Batesville. The city well (No. 255) flows a strong stream of water which has stained the pipe and trough with iron oxide. It is used for general domestic purposes and is considered a wholesome drinking water.

Pearl River County.—The population of this county is very small and the water resources are undeveloped.

Perry County.—Perry is one of the few counties of southern Mississippi, except the Gulf coast counties, which have artesian wells. A large number of flowing wells, ranging in depth from 325 to 380 feet, have been drilled in and near Hattiesburg. Very little effort has been made to get flowing wells in other portions of the county. In the eastern part, along Leaf River and its northern tributaries, flowing wells should be obtained at about the same horizon as those at Hattiesburg.

The town of Hattiesburg is supplied with water from flowing wells, one 4 inches and another 6 inches in diameter, the water being pumped from a reservoir through the town. This water is alkaline and chalybeate.

Pike County.—In the greater part of this county the Lafayette lies deep on the Grand Gulf clays. Wherever the former is cut through by erosion large springs occur.

Pontotoc County.—The uppermost formation of the Cretaceous comes to the surface in the eastern part of Pontotoc County, and the lower Tertiary appears in the west. The Ripley sands are water bearing. Along the headwaters of Tallahatchie River, in the north-central part, flowing wells are obtained. Over the remainder of the county the elevation of the country lying west of the catchment area of the Ripley sands is too great to get flowing wells, except, perhaps, along the headwaters of Shooner River, in the southwestern part.

Efforts have been made to get flowing wells at the town of Pontotoc, but without success. It should be remembered that this town is located on the crest of Pontotoc Ridge, the northern extension of which is the source of the flowing wells in the vicinity of Ecru. Pontotoc is more than 100 feet higher than Ecru, where the water rises only to the surface. It is very improbable, therefore, that flowing water could be obtained at Pontotoc. Considering the dip of the underlying Cretaceous to be constant, good pumping water from the Tuscaloosa-Eutaw horizon may be expected at a depth of 893 feet, and it should rise to within 250 feet of the surface. The same water in the southern part of the county would be obtained at a still greater depth.

Prentiss County.—The high east-west ridge across this county makes it impossible to get flowing wells anywhere within it. Good pumping water could be obtained from the Tuscaloosa sands, at a maximum depth of 500 feet, in the vicinity of Booneville. The water would rise to within about 260 feet of the surface, and perhaps less, depending on the elevation of the catchment area to the east.

Quitman County.—The Wilcox sands, which furnish the flowing wells at Batesville, continue their westward dip of about 16 feet to the mile, and in Quitman County the wells range in depth from 636 to 860 feet. One well furnishes 100 gallons per minute from a 2½-inch pipe. One of the deep wells at Riverside (No. 278) has the following interesting log:

Log of well at Riverside.

	Feet.
9. Sand and silt	40
8. Blue mud	45
7. Water-bearing sand	50
6. Gravel sand	40
5. Soapstone alternating with sand	220
4. Rock	1
3. Soapstone and rock	50
2. Green sand to lignite which is 10 inches thick	10
1. Soapstone containing mica and white sand	180
Total depth	636

Nos. 1 to 5, inclusive, are strata in the Wilcox, while the upper 175 feet belong to the Port Hudson formation. The 370 feet represented by Nos. 3, 4, and 5 are the upper clay of the Wilcox, which is shown in the Memphis well and outcrops in the river bed at Grenada.

Rankin County.—Flowing wells are not possible in this county, except along Pearl River. Wells in the southern part of the county are supplied from the Grand Gulf formation. The water is often strongly mineral, as it comes from lignitic clays and sands. Strong springs are common in the western part of the county. Some of these spring waters are hauled to Jackson in large demijohns and sold for drinking water.

Scott County.—About half of this county is prairie land of the Jackson formation. The town of Forest is in a belt of level land or "flat woods," 5 to 10 miles wide, running from the southeast to the northwest corner of the county. When water is found in this prairie soil it is very unsatisfactory for drinking, as it contains a large amount of lime. At Forest one well is reported to be 520 feet deep. This failed during the fall of 1903 and a new one was drilled later. Here and there over the prairie are hills and ridges covered with remnants of the Lafayette, which furnish excellent water in shallow wells and springs. Good deep-well water can be obtained from the Claiborne horizon at 500 to 700 feet. In some sections of the county the water will rise very near the surface.

Sharkey County.—No wells are reported. Flowing wells are not to be obtained. Good wholesome water from the Claiborne horizon would be reached at about 1,500 feet.

Simpson County.—Water is obtained from the Grand Gulf and the Lafayette. Flowing wells could doubtless be obtained along Pearl River at a maximum depth of 500 feet.

Smith County.—The elevation is high and the water is poor in the northern part of the county. Flowing wells from the lower Grand Gulf are obtained in the southeastern part, in the vicinity of Taylorsville. The deepest (No. 281) in the county has a depth of 1,135 feet. The strata passed through are as follows (no thicknesses are given): Surface clay, sand, blue sand mixed with sand, sand rock, blue mud, and sand. Water was obtained in white sand.

Sunflower County.—Only two wells have been reported from Sunflower County. The temperature of the Moorhead well (No. 287) is 60° (?). The Claiborne horizon lies at a depth of more than 1,000 feet in the western part of the county, and the water will not generally rise above the surface. In eastern Sunflower County it is possible to get good flowing wells at about 900 to 950 feet. In boring for water a depth of 900 feet on the eastern border of the county should be counted on, with an additional 25 feet for each mile to the west.

Tallahatchie County.—This county, like Leflore County, which lies just south of it, has high hills in the adjoining county to the east. Drillers say that it is more difficult to obtain flowing wells in Tallahatchie than in Leflore County. This is perhaps due to two causes. The artesian water in Leflore comes from the Claiborne horizon, while that in Tallahatchie comes from the Wilcox. There is also a possibility that the water-bearing sands underlying Tallahatchie County may be much finer and mixed with clay, which would make the water horizon less certain.

Tate County.—No artesian wells are found in Tate County. The wells in the eastern edge of the Yazoo Delta in this county along Coldwater River have the following general section: Surface clay 15 to 20 feet, gravel 12 to 15 feet, red sand merging into white sand, below which come pipe clay and water-bearing sand. East of the delta good shallow wells and springs are found at the base of the Lafayette.

Tippah County.—The eastern part of Tippah County has a north-south line of high hills in which the Ripley formation outcrops. This formation furnishes fine water, which has not been found to rise above the surface. There is a possibility of getting flowing wells on Tippah Creek, in the western part of the county.

The outcrop of the Midway limestone is marked by a line of springs, the water of which is chalybeate. It obtains its iron in passing through the sandy marl lying above the limestone.

Tishomingo County.—This county contains numerous springs along the contact of the older Devonian and Carboniferous rocks with the lower Cretaceous. The Iuka Springs are noted for their curative properties.

Tunica County.—Flowing wells can be obtained in the eastern half of Tunica County at a maximum depth of 875 feet. The water will probably not rise above the surface along the western border, but will reach within an easy pumping distance.

Union County.—Central Union and north-central Pontotoc counties contain a small area of artesian wells. The source of the water is the lower Ripley sands on the west slope of Pontotoc Ridge, in the eastern part of these counties. The catchment area of the Ripley is comparatively limited, and the head of the water has been considerably lowered by increasing the number of wells. The first wells at New Albany had a very high pressure, but most of them now have to be pumped. Water is generally reached at a depth of less than 250 feet.

Warren County.—Only one deep well is reported from Warren County. This is the Vicksburg well, which is 1,060 feet deep, and in which, when it was completed, the water rose to the surface. Wells south of Vicksburg obtain their supply from the Grand Gulf and the Lafayette; those north of the town from the Lafayette only.

Washington County.—No flowing wells are reported from Washington County. The western part is too far removed from the sources of the water to obtain flowing wells, but artesian wells should be obtained in the eastern part at a maximum depth of 1,200 feet and perhaps less. Flowing wells are obtained at Tchula, in central Holmes County

at a depth of about 770 feet. If we assume a westward dip of 25 feet per mile, the same water can be reached at Belzona at about 1,150 feet.

The following log was given of the deep well (No. 307) at Leland. This well is 512 feet in depth and rises to within 14 feet of the surface.

Log of deep well at Leland.

	Feet.
Buckshot clay	2
Fine sand	138
Hard gravel	14
Hard blue clay	298
Coarse gray sand	60
	512

Water was obtained in the last 60 feet of sand. In the 298 feet of hard clay there were six different strata of rock from 6 inches to 2 feet thick. The driller reports that these rock strata are persistent over this region of the Yazoo Delta. In some wells ten or twelve different strata are found, and in others not more than three or four. The maximum thickness of these rocks is 4 feet. The driller further says that the hard gravel is very persistent, is always found at about the same depth, and is never less than 10 nor more than 14 feet thick. The water carries 9 grains of solid matter to the gallon, 7 grains being soda.

Wayne County.—There are numerous flowing wells along Chickasawhay River in Wayne County. The water comes from the Claiborne horizon and is usually red and of an alkaline character.

Well No. 309, at Waynesboro, yields red water, which contains 72 grains of sodium carbonate to the gallon and considerable iron. All the wells at Waynesboro start in a thin sandy layer, possibly Lafayette, which rests upon the Vicksburg, and reach the lower Lisbon beds, from which they obtain red water.

Webster County.—No deep wells are reported. Water is supplied from shallow wells.

Wilkinson County.—No deep wells are reported. Water is supplied from shallow open wells.

Winston County.—Plenty of water is obtained from the Wilcox, but at many localities it is very bad, owing to the great amount of lignitic clay.

Yalobusha County.—There are two artesian areas in Yalobusha County, one in the vicinity of Coffeeville and the other at Water Valley, but there are, no doubt, other undeveloped areas along the lower streams. The source of the artesian water at the above-mentioned places is the lower division of the Wilcox.

There are eight flowing wells in the town of Coffeeville and three others near the city limits. They range in depth from 160 to 400 feet. The log of well No. 315 showed 40 feet of surface sand; 100 feet of greensand; then gravel, lignite, and sand to water, which was obtained at 238 feet. Where the water-bearing sand was encountered, the drill dropped 8 or 9 feet into it. This is a white sulphur water and is said to be wholesome.

Wells are easily obtained in Shooner River Valley, and the drillers guarantee a flowing well at a cost of $100.

Yazoo County.—One of the deepest wells (No. 319) in the State was recently drilled at Yazoo. It failed to get flowing water at a depth of 1,567 feet, though there are flowing wells in the town of less than half that depth. The temperature of one of the flowing wells southwest of town is reported to be 70° F.

DEEP-WELL RECORDS

Partial list of deep wells

[Reported to the United

No.	County.	Town.	Owner.	Location.			Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
				Township.	Range.	Section.					
								In.	Feet.	Feet.	Feet.
*1	Adams	Natchez	Waterworks Co				1901	6	340		− 30
*2	do	do	Oil mills					6	170		− 20
3	do	do	Gas Company					6	165		− 10
*4	do	do	Electric Light, Heat and Power Co.					6	430		−160
5	do	do	C. S. Bennett				1899	10	115	115	− 85
6	do	do	Cotton mills No. 2				1902	8	175		− 8
7	do	do	Natchez ice factory				1902	6	517	500	− 8
8	do	do	do				1902	6	300	264	− 36
*9	do	Pine Ridge	W. P. Henderson				1896	6	97	85	− 85
*10	Alcorn	Corinth	E. S. Candler	2	2	7	1900	6	100	100	− 20
*11	do	do	Waterworks Co				1903	12	345		− 20
*12	Attala	Kosciusko	A. M. Hanna	14	7	21	1899	4½	276	200	− 76
13	Bolivar	Cleveland	Sillers & Owens	22	5	21	1901	3	1,000	1,000	+ 0
14	do	do	C. S. Glassco	22	5	21	1901	4	1,000	1,000	+ 0
15	do	O'Reilly	O'Reilly	21	5	23	1901	4	1,002		+ 0
16	Carroll	Carrollton	A. H. George	19	4	6	1898	8	85	70	− 70
*17	do	do	City				1900	4	1,250	{ 300 450 }	−
*18	do	do	Waterworks Co	19	3		1900	4	400	400	+ 0
19	do	Vaiden	S. E. Turner	17	5		1901	2	105	105	+ 12
*20	Chickasaw	Okolona	City				1899	6	550	550	− 80
*20a	do	do	Mobile and Ohio Railroad.						548	473	− 22
21	Choctaw	Chester	J. T. McCafferty	18	10	15	1892	10	86	80	− 60
*21a	Claiborne	Hermanville	W. G. Herrington	11	4	3	1878	12	86	75	− 75
*22	Clarke	Barnett	A. Krouse	2	14	20	1899	4	350	125	−
*23	do	do	Smith's Mill Co	2	14	31	1902	6	600		−
*24	do	De Soto	Town	2	15	36	1898	3	190	150	+ 3
*25	do	Enterprise	do	4	14	24	1895	2	156	150	+ 20
*26	do	do	R. M. Buckley	4	15	19	1896	3	198		− 2
27	do	do	John Kemper	4	14	26	1901	3	150	150	+ 15
28	do	do	Bonny	4	14	23	1901	3	200		+ 10
*29	do	do	S. J. Taylor	4	14	23	1900	3	210	210	− 3
30	do	do	Mrs. O'Ferral	4	15	19	1900	3	400	210	− 20
*31	do	Quitman	J. B. Evans	2	15	1	1898	3	232	232	+ 15
32	do	do	Mississippi Lumber Co.	2	15	2	1899	3	179	179	+ 20

* See text, pp. 27-29, for additional data.

IN MISSISSIPPI.

in the State of Mississippi.

States Geological Survey.]

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
Pump	Hard		None apparent.	None apparent.	Lafayette	Grand Gulf	*1
do	do		Neither	do	Loess	Base of Lafayette	*2
do			do		do	Lafayette	3
do			None apparent.		do	Grand Gulf	*4
Bucket	Good		Neither		do	Lafayette	5
Pump	Hard		do	Little	do	Grand Gulf	6
do	do	50	None apparent.	None apparent.	Lafayette	do	7
Compressed air.	Good	70	do	do	do	do	8
Bucket	Hard			Easily lowered.	Loess	Lafayette	*9
Pump	do		None apparent.	None apparent.	Lafayette	Eutaw	*10
do	do	20	do	do	do	Tuscaloosa	*11
do	do	100	do	Little	Claiborne	Wilcox	*12
Flows	Soft	75	None		Port Hudson.	do	13
do	do	100	None apparent.	None apparent.	Alluvial bottom.	Claiborne	14
do	do	100	None		Port Hudson.	Wilcox	15
Bucket	do		None apparent.				16
		0			Lafayette?	Claiborne	*17
Flows	Soft	62	None apparent.		Alluvial bottom.	do	*18
do	do		Neither				19
Compressed air.	do	138	None apparent.	None apparent.	Cretaceous	Eutaw	*20
Pump					Lafayette	do	*20a
Pulley	Hard	½	do	Easily lowered.	do	Wilcox	21
Bucket				None	do	Grand Gulf	*21a
None					Jackson	Claiborne	*22
do					do	do	*23
Flows	Soft, alkaline.	⅓	Decreased		Claiborne	do	*24
do	Soft	15	Slight		Alluvial soil	Wilcox	*25
Pump	do		Decreased	Lowers easily.	Lafayette	do	*26
Flows	do		Little		Alluvium	do	27
do	do		do		Lafayette	do	28
Pump	do		Decreased slightly.	Slight	do	do	*29
do	do		Decreased	Easily lowered.	do	do	30
Flows	do	3	Variable	do	do	do	*31
do	do	3		do	do	do	32

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Range.	Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	Feet.	Feet.	Feet.
*33	Clarke	Quitman	Town	2	15	1	1898	3	175	175	+ 15
*34	do	Shubuta	do				1898	2	400		+ 15
*35	do	do	Weems				1901	2	422	400	+ 20
36	do	do	W. P. Cooper				1902	6	420	375	+ 30
37	do	do	W. H. Paterson				1900	2	400	400	+ 20
38	do	do	F. H. Floyd				1901	2	400	400	+ 20
39	do	do	D. C. Ward				1902	2	170		+ 10
40	do	do	W. P. Cooper				1900	2	165		+ 0
41	do	do	Moseley				1901	2	175	160	+ 10
42	do	do	Patterson				1901	2	160		+ 10
*43	do	do	Cooper's mill				1897	2	145		− 20
44	do	do	Stovall				1900	2	165		+ 15
*45	do	do	A. Johnston	1	16	25	1896	2	280	260	+ 20
46	do	do	Eggerton				1900	2	175		+ 10
47	do	do	Floyd Hotel				1899	2	165		+ 10
48	do	do	Poole & Brown				1900	2	175		+ 10
49	do	do	Brown's mill				1901	2	165		+ 10
50	do	do	Leggett				1902	2	170		+ 10
51	do	Stonewall	T. L. Wainwright	3	15E	5	1897	2½	300	250	+ 20
*52	Clay	West Point	City				1895	3	600	600	+ 1
*52a	do	Cedar Bluffs	do						650	650	−100
53	Coahoma	Eagles Nest	James L. Alcorn's estate.	28	3	22	1898	1½	825	825	+ 0
*53a	do	Clarksdale	Town.				1897	2½	876	876	+ 10
54	do	Jonestown	Geo. Richberger	28	6		1902	2	800	700	+ 0
*55	do	Lyon	Lamar Fontaine	27N	3 W	18	1901	4	975	970	+ 35
*56	Copiah	Wesson	Dr. E. A. Rowan	9	8E	34	1890	36	120	120	−100
*56a	Grenada	Grenada	City						620	490	+ 0
*57	Hancock	Bay St. Louis	College				1888	3	738		+ 42
*58	do	do	do				1892	3	750		+ 42
*59	do	do	R. E. Craig				1901	3	529		+ 17
*60	do	do	G. W. Dunbar Sons' Co.				1888	2	250		+ 20
*61	do	do	do				1898	3	338		+ 35
*62	do	do	Dr. F. Loeber				1890	3	669	656	+ 40
*63	do	do	McClyde Turpentine Co.				1903	3	328		+ 25

* See text, pp. 28-30, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
Flows	Soft	3	Variable		Lafayette	Wilcox	*33
do	do	20	Decreased		Jackson	Claiborne	*34
do	do		None apparent.		Jackson	Claiborne	*35
do	do	40	do		do	do	36
do		40	do		do	do	37
do	Soft	40	do		do	do	38
do	do	15	do		do	do	39
do	do	15	Decreased slightly.		do	do	40
do	do	15	None apparent.		do	do	41
do	do	15	do		do	do	42
	do	20	do		do	do	*43
Flows	do	10	do		do	do	44
do	do	15	Decreased		do	do	*45
do	do	10	None apparent.		do	do	46
do	do	10	Slight decrease.		do	do	47
do	do	10	None apparent.		do	do	48
do	do	10	do		do	do	49
do	do	15	do		do	do	50
do	do	25	Decreased 25 per cent.		Lafayette	Wilcox	51
do	Best		None apparent.		do	Tuscaloosa	*52
					Selma	do	52a
Flows	Soft	8	None apparent.		Alluvium?	Wilcox	53
do	do	3	do		do		*53a
do	do	8	do		River bottoms.	Wilcox	54
do	do	22	do		Port Hudson	do	*55
Pump	Hard		Neither	Slight	Lafayette	Grand Gulf	*56
Flows					do	Wilcox	*56a
do	Soft	8	Decreased		Post-Tertiary.		*57
do	do	5	do		do		*58
do	do	100	None apparent.		do	Post-Tertiary	*59
do	do	35	do		do	do	*60
do	do	100	do		do	do	*61
do	do	40			do		*62
do	do	20	None apparent.		do	Post-Tertiary	*63

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Location. Range.	Location. Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	*Feet.*	*Feet.*	*Feet.*
*64	Hancock	Bay St. Louis.	Chas. Sanger				1892	3	385	385	+ 15
*65	do	do	do				1889	3	384	361	+ 30
*66	do	do	St. Stanislaus College.				1888	2	420	190, 420	+ 20
*67	do	do	St. Joseph's Academy.				1888	2	418	418	+ 20
68	do	do	R. Thelhiard				1893	2½	345	315	+ 13
*69	do	do	Tally Lumber Co.				1903	4½	150		+ 23
70	do	Logtown	Bush & Johnson				1889	2½	620		+ 25
*71	do	Nicholson	D. Carver	6	17	34	1896	2	250	225	+ 0
72	do	Picayune	J. W. Simmons	6	17	15	1895	2	500	500	+ 25
*73	do	Waveland	P. Helwig				1891	2½	356		+ 15
*74	do	do	Mr. Bookta					3	366	320	+ 0
*75	do	do	A. Matranger				1894	3	438	419	+ 15
*76	do	do	F. Caseneuve					3	376	357	+ 15
77	do	do	M. A. Dauphin				1889	2½	483	467	+ 23
*78	do	do	T. R. Fell				1888	2½	461	410	+ 20
79	do	do	Paul Conrad				1889	3	432	412	+ 16
80	Harrison	Biloxi	Barataria Canning Co.				1886	3	620		+ 75
81	do	do	Biloxi Canning Co.				1902	3	715		+ 65
82	do	do	Biloxi Cemetery				1896	2½	580		+ 35
83	do	do	Biloxi Ice Co.				1894	3½	920		+ 75
84	do	do	Jno. Caraway				1896	2½	560		+ 30
85	do	do	Mrs. Carter				1896	2½	600		+ 30
86	do	do	City				1889	2½	420		+ 25
87	do	do	do				1889	2	414		+ 20
88	do	do	do				1889	4½	860		+ 80
89	do	do	F. H. Dunbar				1891	2	420		+ 20
90	do	do	Thos. Gill				1895	3	720		+ 70
91	do	do	H. Howard				1885	2	420		+ 25
92	do	do	F. T. Howard				1885	2½	415	400	+ 30
93	do	do	do				1886	4½	920		+ 80
94	do	do	do				1886	2½	420	410	+ 30
95	do	do	Ice factory					3½	890		+ 80
96	do	do	E. C. Joullian				1901	2½	650		+ 60
97	do	do	L. Lopez				1886	2	600		+ 27
98	do	do	do				1886	2½	620		+ 60
99	do	do	do				1897	3	700		+ 70
100	do	do	J. H. Keller				1886	2½	420		+ 30
101	do	do	Waterworks Co.					4½	860		+ 53
101a	do	Bond	J. E. North						690	530	−160

* See text, pp. 30-31, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
Flows	Soft	5	Fluctuates		Post-Tertiary.		*64
do	do	30	None apparent.		do		*65
do	do	40	do		do	Post-Tertiary	*66
do	do	40	do		do	do	*67
do	do	45	do		do		68
do	do	100	do		do	Post-Tertiary	*69
do	do	60	do		do	Grand Gulf	70
do	do	28	Neither		Port Hudson	Grand Gulf	*71
do	do	27	do		Post-Tertiary.		72
do	do	25	None apparent.		do		*73
do	do	75	do		do		*74
do	do	30	do		do		*75
do	do	30	do		do		*76
do	do	25	do		do		77
do	do	30	do		do		*78
do	do	30	do		do		79
do	do	150	do		do		80
do	do	125	do		do		81
do	do	70	do		do		82
do	do	300	do		do		83
do	do	70	do		do		84
do	do	60	do		do		85
do	do	50	do		do		86
do	do	35	do		do		87
do	do	425	do		do		88
do	do	40	do		do		89
do	do	150	do		do		90
do	do	50	do		do		91
do	do	40	do		do		92
do	do	175	do		do		93
do	do	50	No change		do		94
do	do	300	None apparent.		do		95
do	do	100	do		do		96
do	do	50	do		do		97
do	do	100	do		do		98
do	do	175	do		do		99
do	do	60	do		do		100
do	do	450	do		do		101
do	do		do		do	Grand Gulf	101a

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Range.	Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	*Feet.*	*Feet.*	*Feet.*
*102	Harrison	Delisle	W. S. Keel	8	13	2	1898	2	380		+25
103	do	Gulfport	U. S. Marine Hospital, Ship Island.				1900	3	760		+50
104	do	do	Ice factory				1891	2½	540		+25
105	do	do	Chautauqua Circle				1891	3	680		+50
106	do	do	G. & S. I. R. R				1896	2½	680		+25
107	do	do	do				1899	3	920		+75
108	do	do	do				1903	4½	960		+80
109	do	Handsboro	—— Zimmerman				1896	2½	500		+15
110	do	do	H. Leinhard				1896	2½	700		+20
111	do	do	Leonard Lumber Co.	7	11	25	1895	3	700		
*112	do	Howison	Howison Lumber Co.				1897	2	1,480	1,400	−35
113	do	Longbeach	F. Jahenski				1896	2½	580		+25
114	do	do	—— McCaughn				1897	2½	600		+35
114a	do	Lyman	City						480	375	
115	do	Mississippi City.	F. W. Elmer				1896	4½	860	850	0
116	do	do	L. & N. R. R				1885	2	520		+20
117	do	do	Mr. Clemaceau				1897	3	740		+80
118	do	do	C. P. Ellis				1896	3	720		+75
119	do	do	Mr. De Buys				1895	2½	640		+30
120	do	do	Mr. Soria				1885	2	514		+20
121	do	Nugent					1902	2½	300	300	+30
*122	do	Pass Christian.	R. M. Walmsley				1902	3	720		+50
*123	do	do	Wm. Hardin				1892	3	620		+47
*124	do	do	C. L. Chaptal				1892	2½	543		+25
*125	do	do	A. Swanson				1892	2½	560		+30
*126	do	do	E. Saunders				1884	2	575		+25
*127	do	do	City				1885	2	420		+30
*128	do	do	do				1887	2½	520		+35
*129	do	do	do				1893	2	620		+30
*130	do	do	do				1890	3	640		+50
*131	do	do	do				1890	3	625		+60
*132	do	do	do				1890	3	840		+80
*133	do	do	G. H. Taylor				1898	2	420		+27
*134	do	do	do				1898	3	725		+80
*135	do	do	E. Connery, jr				1886	2	520	510	+35
*136	do	do	L. C. Tallon				1901	3	640		+40
*137	do	do	A. Mullinburger				1888	2½	514		+40

* See text, p. 31, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Contiuued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
Flows	Soft	25	None apparent.		Post-Tertiary.	Lafayette	*102
do	do		do		do	Grand Gulf	103
do	do	60	do		do		104
do	do	80	do		do		105
do	do	60	do		do		106
do	do	150	do		do		107
do	do	175	do		do		108
do	do	60	do		do		109
do	do	100	do		do		110
do	do	175	Variable		Alluvium	Pascagoula	111
		0					*112
Flows	Soft	60	None apparent.		Post Tertiary.		113
do	do	70	do		do		114
					do	Grand Gulf	114a
Flows	Soft	450	None		do	do	115
do	do	50	None apparent.		do		116
do	do	160	do		do		117
do	do	150	do		do		118
do	do	70	do		do		119
do	do	50	do		do		120
do	do	60	do				121
do	do	150	do		Post Tertiary.		*122
do	do	170	Little		do		*123
do	do	60	do		do		*124
do	do	70	do		do		*125
do	do	60	do		do		*126
do	do	40	do		do		*127
do	do	50	do		do		*128
do	do	40	None apparent.		do		*129
do	do	150	do		do		*130
do	do	150	do		do		*131
do	do	225	do		do		*132
do	do	25	do		do		*133
do	do	200	do		do		*134
do	do	60	None		do	Grand Gulf ?	*135
do	do	80	None apparent.		do		*136
do	do	50	do		do		*137

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Location. Range.	Location. Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	*Feet.*	*Feet.*	*Feet.*
*138	Harrison	Pass Christian.	W. R. Wilson				1898	2½	510		+ 25
*139	do	do	Mrs. Watt				1896	3	670		+ 75
*140	do	do	E. Connery, sr.				1887	2½	510		+ 50
*141	do	do	Jno. Curran				1894	3	620		+ 40
*142	do	do	Jno. A. Sutter				1894	2½	514		+ 45
*143	do	do	S. F. Heaslip				1895	2½	620		+ 40
*144	do	do	E. Hocaday				1895	2	520		+ 30
*145	do	do	Mexican Gulf Hotel				1888	2½	520		+ 30
*146	do	do	J. H. Menge				1890	2½	600		+ 30
*147	do	do	H. Buddig				1889	2½	600		+ 25
*148	do	do	J. M. Ayer				1891	2	540		+ 25
*149	do	do	do				1891	2	540		+ 25
*150	do	do	Pass Packing Co				1899	3	920		+ 80
*151	do	do	Doctor Perault				1903	3	1,020		80
*152	do	do	Magnolia Hotel				1902	3	900		+ 89
*153	do	do	H. Payne				1890	2½	614		+ 30
153a	do	Ship Island	Gov. light-house					2	750	700	+
154	do	Saucier	Biloxi Lumber and Export Co.				1897	3	720		
155	do	Wortham	J. C. Wilmoth	6	12	1	1902	4	836	786	+ 15
156	Hinds	Jackson	Ice factory				1896	6	604		− 58
157	do	do	Baptist Orphanage				1900	6–4½	200	180	−120
*157a	do	Bolton	City				1903	6	1,517	1,020	− 80
158	Holmes	Durant	I. C. R. R					5	375		+ 0
158a	do	do	City				1905	6	500	500	+ 1
158b	do	Cruger	Ed. Archer	17	1	26	1897	2	800	700 and 800	+
158c	do	Lexington	G. A. Wilson					2	800		+
*159	do	Pickens	W. S. Gordon?	12	3	15	1901	4–2	265	265	+ 2
*160	do	Tchula	City				1900	4–2	1,125		+ 85
161	do	do	W. B. Jones	16	1	5	1902	3–2	770	770	
*162	do	West	Dr. L. S. Rogers	15	5	3	1901	3	160	150	+ 15
*163	Jackson	Fontainebleau	J. B. Carson				1893	2½	720	700	+ 50
*164	do	do	A. E. Lewis				1889	2½	625	600	+ 40
165	do	Moss Point	Dantzler Lumber Co.				1889	2½	560		+ 25
*166	do	do	Denny Lumber Co				1902	3	900		+ 20
*167	do	do	F. H. Lewis				1902	6–4	1,550	650	+ 50

* See text, pp. 31–33, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum	No.
		Gals.					
Flows	Soft	60	None apparent.		Post Tertiary.		*138
do	do	170	Little		do		*139
do	do	50	None apparent.		do		*140
do	do	100	do		do		*141
do	do	60	do		do		*142
do	do	70	do		do		*143
do	do	50	do		do		*144
do	do	60	do		do		*145
do	do	60	do		do		*146
do	do	50	do		do		*147
do	do	50	do		do		*148
do	do	50	do		do	Post-Tertiary	*149
do	do	250	do		do		*150
	do	250	do		do		*151
Flows	do	250	do		do	Pascagoula marl.	*152
do	do	60	do		do		*153
Flows		50			Recent	Pascagoula	153a
		0					154
do	Soft	75	Decreased	Lowered slowly.	Lafayette?	Pascagoula	155
Steam pump	Good	35	Little	Slight	do	Upper Claiborne.	156
do	Hard	30	do	do	do	Under Jackson marl.	157
do	Soft		None	None	Grand Gulf.	Wilcox	*157a
Flows	do		None apparent.		Second river bottoms.	do	158
do	do				Lafayette	Claiborne	158a
do		90		None	Port Hudson.	do	158b
do					do	do	158c
do	Hard	12	None apparent.		Second river bottoms.	do ?	*159
do	Soft	130	do				*160
do	do	200	None				161
do	do	20	None apparent.		Lafayette sand.	Wilcox	*162
do	do	70	do		Post Tertiary.	Pascagoula	*163
do	do	60	do		do	do	*164
do	do	40	do		do	do	165
Flows	Soft	25	do		do		*166
do	Hard	400	Neither			Grand Gulf?	*167

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Range.	Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	Feet.	Feet.	Feet.
*168	Jackson	Ocean Springs	J. J. Kuhn	....	....	....	1891	2½	880	......	+80
169	.....do........	.....do........	A. A. McGinnes	....	....	....	1885	2½	620	......	+40
170	.....do........	.....do........	N. B. Smith	....	....	....	1885	2½	514	......	+20
*171	.....do........	.....do........	Wm. De Pass.......	....	....	....	1898	2½	520	......	+30
172	.....do........	.....do........	Chas. Zeigler........	....	....	....	1901	2½	560	......	+30
173	.....do........	.....do........	Mr. Sullivan........	....	....	....	1901	2½	540	......	+25
174	.....do........	.....do........	J. Feitag..........	....	....	....	1888	2½	525	......	+30
175	.....do........	.....do........	John Blank.........	....	....	....	1902	2½	550	......	+50
176	.....do........	.....do........	Captain Benson	....	....	....	1890	2½	550	......	+50
*177	.....do........	.....do........	People's water-works.	....	....	....	1901	3	965	......	+75
*178	.....do........	.....do........	George Rose........	....	....	....	1897	4	900	......	+16
*179	.....do........	.....do........	George Rose, of New York.	....	....	....	1903	8–4	1,200	900	0
*180	.....do........	.....do........	Electric Ice Co......	....	....	....	1903	3	866	......	0
*181	.....do........	Scranton	City................	....	....	....	1897	6	800	......	+43
*182	.....do........	.....do........	F. H. Lewis.........	....	....	....	1891	2½	720	......	+30
*183	Jones.........	Ellisville	County..............	7	12	5	1902	6	1,300	350	−20
*184	.....do........	Laurel........	Kingston Lumber Co.	....	....	....	1902	6	365	325	−40
185	.....do........	.....do........	Cotton mills........	9	11	32	1902	6	210	200	−40
*186	.....do........	.....do........	Waterworks........	9	11	32	1901	8	370	370	−40
187	.....do........	.....do........	Eastman, Gardner & Co.	9	11	32	1900	6	215	200	−40
187a	Kemper......	Forrest.......	City................	....	....	....	......	....	219	217	−90
188	Lafayette	Oxford	.....do..............	8	3	28	1896	10	185	100	−50
189	.....do........	.....do........	University..........	8	3	28	1897	....	185	100	−50
189a	Lamar.......	Lumberton...	Hinton Lumber Co .	....	....	....	......	8	1,800	......	......
*190	Lauderdale...	Lauderdale...	M. & O. R. R........	8	17	24	1902	6	133	......	− 6½
190a	.....do........	Meridian	City................	....	....	....	......	....	900	......	−30
191	.....do........	Lauderdale...	John Nunnery......	8	17	24	1902	2½	108	......	+ 1½
*192	.....do........	.....do........	M. Smith...........	8	17	24	1901	2	216	......	− 7
193	.....do........	.....do........	John Nunnery......	8	17	24	1901	2½	108	......	+ 1½
*194	.....do........	.....do........	M. & O. R. R	8	17	24	1901	6	132	......	− 6½
195	.....do........	Meehan Junction.	Meehan-Rounds Lumber Co.	6	14	33	1902	3	324	......	0
*196	.....do........	.....do........	.....do..............	6	14	33	1902	3	324	......	+ 0
*197	.....do........	Meridian.....	City................	....	....	....	1902	5	305	......	− 5½

*See text, pp. 32–33, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
Flows	Soft	150	None apparent.		Post Tertiary.	Pascagoula	*168
do	do	80	do		do	Clay above Pascagoula.	169
do	do	25	do		do	Post-Tertiary clays.	170
do	do	60	do		do	do	*171
do	do	60	do		do	do	172
do	do	50	do		do	do	173
do	do	60	do		do	do	174
do	do	26	do		do	Post-Tertiary sands.	175
do	do	100	do		do	do	176
do	do	250	Neither		do	Pascagoula	*177
do	do	100	None apparent.		do	do	*178
do	Alkaline		do		do	do	*179
do	Soft	240	do		do		*180
do	do	150	do		do	Pascagoula	*181
do	do	60	do		do	do	*182
	Hard				Lafayette	Grand Gulf?	*183
Pump	Soft	150	None apparent.	None apparent.	do	do	*184
do	do	150	do	do	do	do	185
Compressed air.	do	280	do	None	do	do	*186
do	do	140	do	do	do	do	187
					do	Claiborne	187a
Pump	Soft		None apparent.	Slight	do	Wilcox	188
do	do		do	None observed.	do	do	189
					do	Grand Gulf	189a
Pump	Soft	115	None apparent.	Lowered	do	Wilcox	*190
					do	do	190a
Flows	Soft		None apparent.		do	do	191
Pump	do		do		do	do	*192
Flows	Hard		do		Wilcox	do	193
Pump	do	100	do	Slight	do	do	*194
Flows	Soft	11	Neither		Lafayette	do	195
do	do	11	do		River alluvium.	do	*196
Pumps	Hard				Creek bottom.	do	*197

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Location. Range.	Location. Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	Feet.	Feet.	Feet.
198	Lauderdale	Meridian	City				1902	2½	257		+4
*199	do	do	do				1882	2	905		−20
200	do	do	do				1903	5	305		− 5½
*201	do	do	Ice factory				1890	3	680		−25
*202	do	Siding	W. J. Graham	6	14	22	1895	3	77	40	+22
*203	do	do	Mrs. Martha Maxwell.	6	14	22	1896	3	75		+ 0
204	Lawrence	Silver Creek	A. T. Longino	7	20	10		12	80	70	−70
205	do	do	Dr. B. B. Cowant	7	20	6	1898	10	89	73	−73
*205a	Lee	Baldwyn	Brick Co.						380		− 5
206	do	Guntown	Robt. Gambrell	7	6	12	1870	5	70	70	−40
206a	do	do	City						300		−30
207	do	Nettleton	Jno. McGaughey	11	6	11	1898	4	140	110	+ 0
208	do	Plantersville	R. S. Rodgers	10	6	34	1899	6	160	149	+ 0
209	do	do	Robt. Birmingham	11	6	1	1898	4½	140	140	−60
*210	do	Rusk	L. B. Gandy	10	6	3½	1902	3½	322	300	+ 0
211	do	do	W. S. Brown	11	6	2	1886	36	130	80	+ 4
212	do	Shannon	J. K. Whitesides	11	6	19	1903	4½	300		−15
212a	do	Tupelo	U. S. Bureau of Fisheries.				1903	4½	398	320	+ 0
*212b	do	do	Mo. and Ohio R. R.						436	406	+ 0
212c	do	do	City						300	300	− 8
213	do	Verona	L. T. Taylor	10	6	20	1870	10	285	200	+ 0
214	do	do	do	10	6	19	1889	6	400	285	−60
215	Leflore	Greenwood	A. F. Gardner	19	1	10	1901	4	490	400	+40
215a	do	do	T. B. Minyard					2	266	194	+
216	do	do	T. J. Phillips	19	1	15	1900	4	650	600	+40
*217	do	do	Ice factory				1896	4	650	600	+ 0
218	do	Ittabena	L. J. Young & Co.	19	1	20	1897		597		+35
219	do	do	Mahoney Bros	19	1	20	1897	3	596½		+ 0
220	do	do	R. W. Baird	19	1	13	1896	3	365	348	+ 0
221	do	do	A. Henderson	19	1		1898	2	450		+ 0
*221a	do	Minter City	C. E. Feigler	22	1	15	1900	2	437	420	+40
222	Lincoln	Brookhaven	W. R. Norton	8	6	25	1901	12	60	60	−54
223	do	do	S. P. Oliver	7	8	7	1898	6	155	115	−40

*See text, pp. 33-34, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.*	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
Flows	Hard		None apparent.		Wilcox	Wilcox	198
Motor	do		do	Easily lowered.	do	do	*199
Pump	do				Second river bottoms.	do	200
Steam pump	do		None apparent.	Easily lowered.	Wilcox	do	*201
Flows	Soft		do		Buhrstone	do	*202
do	do		do		do	do	*203
	do		do	Little	Lafayette	Lafayette	204
Bucket	Hard		do	Slight	do	Grand Gulf	205
					Selma	Eutaw	*205a
Bucket	Soft		None apparent.	Slight	Lafayette clay.	Top of Tuscaloosa	206
	Hard				do	Eutaw	206a
Flows	Hard, good.	5	Neither		Selma	Tuscaloosa	207
do	Soft		None apparent.		do	do	208
Pump	Hard		do	Little	do	do	209
Flows	Soft	15	Neither		River bottom.	do	*210
do	do	3	do		Creek bottom.	do	211
Pump	do		None	None	Selma	do	212
Flows	do		do	do	do	do	212a
do	Small		Decreased		Lafayette	Eutaw	*212b
Pump					do	do	212c
Flows	Soft and pure.	10	None apparent.		Selma	Tuscaloosa	213
Pumps	Soft		do	Slight	do	do	214
Flows	do		do		Port Hudson.	Claiborne	215
do		200			do	do	215a
do	Soft	250	Decreased		do	do	216
do	do	275	None apparent.		do	do	*217
do	Soft and good.		do		Alluvium ?	do	218
do	Soft	60	do		do	Lower Claiborne.	219
do	do	100	Decreased 25 per cent.		Port Hudson.	Wilcox	220
do	do	150	Neither		do	do	221
do	do	50	do		do	Claiborne	*221a
Bucket	do		None apparent.	Easily lowered	Lafayette	Base of Lafayette	222
Air lift	do	275	do	None apparent.	do	Grand Gulf	223

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Range.	Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	*Feet.*	*Feet.*	*Feet.*
224	Lincoln	Brookhaven	S. P. Oliver	7	8	7	1898	8	165	......	......
225	Lowndes	Columbus	City	....	....	....	1898	4	682	......	+ 6
*225a	.....do	.....do	Mobile and Ohio R. R.	....	....	....	......	....	420	......	+ 0
*225b	.....do	Artesia	.....do	....	....	....	......	....	597	597	− 18
*226	Madison	Canton	City	....	....	....	1896	4	1,020	......	+ 19
227	.....do	.....do	W. H. Powell	....	....	....	1896	6	850	810	+ 16
228	.....do	Flora	Flora	....	....	....	1896	6	450	......	− 40
229	Marion	Columbia	City	3	18	5	1903	3	420	400	+ 30
229a	.....do	.....do	B. W. Holloway	City.		....	1905	1½	400	400	+ 20
229b	.....do	.....do	G. H. Rankin	3	18	5	1903	2	425	425	+ 25
229c	.....do	.....do	Lamar Herrington	3	18	5	1903	1¼	425	425	+ 35
*230	Marshall	Holly Springs	City waterworks	4	2	6	1898	6	400	320	−175
231	.....do	Hudsonville	E. C. Mahon	2	2	27	1897	8	168	......	−153
232	Monroe	Amory	T. R. Stevens	12	19	36	1897	2½	154	......	+ 15
*232a	.....do	.....do	City	....	....	....	......	2½	199	199	+ 0
232b	.....do	.....do	Railroad	....	....	....	......	....	250	190	+ 0
*233	.....do	Caledonia	L. D. Booth	....	....	....	1878	6	140	......	+ 20
233a	.....do	Crawford	City	....	....	....	......	4	700	......	−110
234	.....do	Gattman	K. C. and B. R. R.	13	16	32	1899	6	623	620	+ 27
234a	.....do	Muldon	Mobile and Ohio R. R.	....	....	....	......	....	620	......	− 83
*235	Montgomery	Winona	Oil and Mining Co.	19	5	25	1899	6	412	395	− 60
236	.....do	.....do	Electric Light and Ice Co.	....	....	....	1901	10–8–6	400	......	− 75
237	Neshoba	Dixon	Chas. C. Roberts	9	10	1	1895	40	75	......	− 70
*238	Newton	Chunkey	Wm. Harris	6	13	34	1898	2¾	160	160	+ 4
239	.....do	.....do	Jos. Sharp	5	13	13	1900	2½	150	150	+ 4
240	.....do	.....do	D. L. Ragland	5	13	35	1898	3	131	128	+ 0
241	.....do	Hickory	J. J. Barber	6	12	36	1898	3	150	150	+ 8
*242	.....do	.....do	W. H. Galaspy	6	12	36	1898	2½	300	300	+ 2
243	.....do	.....do	J. H. Brown	6	6	13	1897	2½	150	150	+ 10
244	Noxubee	Bigbee Valley	A. G. Cunningham	16	19	16	......	....	500	391	+ 20
244a	.....do	Cooksville	W. S. Permenter	13	19	18	1898	6	500	450	− 30
*244b	.....do	Brookville	Mobile and Ohio R. R.	....	....	....	......	....	657	657	− 60
*245	.....do	Cliftonville	J. B. Cunningham	....	....	....	......	....	451	391	− 0
*246	.....do	Ravine	J. O. Poindexter	....	....	....	......	....	725	725	− 26
247	.....do	.....do	Sebe Gavin	....	....	....	......	....	431	431	+ 16
248	.....do	Macon	G. N. Ladd	....	....	....	1850	3¼	769	......	− 0

*** See text, pp. 34-36, for additional data.**

IN MISSISSIPPI—Continued.

in the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
....	Soft....	275	None apparent	None apparent	Lafayette...	Grand Gulf......	224
Flows......	....do...		.....do.......		Selma.......	Tuscaloosa......	225
.....do......		130			.....do......	.....do..........	*225a
					.....do......	Eutaw..........	*225b
Flows......	Soft	170	None apparent	None apparent	Jackson....	Wilcox..........	*226
....do......	....do...	88	Neither.......		.....do......	Claiborne?.......	227
Pump......	....do...		.....do.......		.....do......	.....do..........	228
Flows......	....do...	25	None apparent		Second river bottoms.	Grand Gulf?.....	229
.....do......	....do...	30	.....do.......		River bottoms.	Grand Gulf......	229a
.....do......	....do...	60	.....do.......		Bottom.....	.....do..........	229b
.....do......	Sulphur	25	.....do.......		.....do......	.....do..........	229c
Steam pump	....do...	100	.....do.......	None apparent	Lafayette...	Wilcox..........	*230
Bucket.....	Hard...		Little.........	Easily lowered.	.....do......	.....do..........	231
Flows......	Soft....	8	None apparent		Selma.......	Tuscaloosa......	232
.....do......	Iron....	25	.....do.......		Eutaw......	.....do..........	*232a
.....do......					Lafayette...	.....do..........	232b
.....do......	Hard...				Tuscaloosa .	.....do..........	*233
						.....do..........	233a
Flows	Hard...	15	None apparent		Lafayette...	.....do..........	234
Steam pump					.....do......	.....do..........	234a
Air lift......	Soft....	20	.....do.......	None..........	Creek bottoms.	Wilcox..........	*235
Pump......	Iron and alkaline, soft.	100	.....do.......		Lafayette? .	.....do..........	236
....	Soft....	½	.....do.......	Easily lowered	.....do......	Lafayette........	237
Flows......	....do...	1	.....do.......		Alluvial....	Wilcox..........	*238
.....do......	....do...	5	.....do.......		River bottoms.	.....do..........	239
.....do......		5	.....do.......		.....do......	.....do..........	240
.....do......	Soft....		Slight.........		.....do......	Claiborne........	241
.....do......	....do...	34	None apparent		Second river bottoms.	Wilcox..........	*242
.....do......	....do...	5	.....do.......		River bottoms.	.....do..........	243
.....do......	....do...		.....do.......		.....do......	.....do..........	244
Pump......	Soft, alkaline.		.....do.......	Lowered.......		Tuscaloosa......	244a
					Selma.......	Eutaw..........	*244b
Windmill...	Soft....				.....do......	.....do..........	*245
Hand pump	...do....				.....do......	.....do..........	*246
Flows......	...do....				Aluvium....	.....do..........	247
Windmill...	...do....		None apparent	Slight.........	Selma.......	Tuscaloosa......	248

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location.			Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
				Township.	Range.	Section.					
								In.	Feet.	Feet.	Feet.
*249	Noxubee	Macon	Mobile and Ohio R. R.				1898	3	769	730	+ 8
*250	do	do	A. T. Dent	15	17	33	1898	6–4	800	750	− 14
*251	do	Shuqualak	City	1	17	16	1899	6	910	910	− 10
252	Oktibbeha	Osborn	A. A. Montgomery						485	485	− 30
*253	do	Starkville	do	19	14	3	1900	8	908		−130
*254	do	do	Agricultural and Mechanical College.	18	14	3	1899	8	900	800	−129
*255	Panola	Batesville	City				1902	4	302	300	+ 20
256	do	Longtown	Dr. Crenshaw	7	9	6	1902	2	580	520	+ 0
*257	Perry	Barbara	A. J. Thomas	1	10	3	1897	12	72	62	− 62
*258	do	Brown	A. G. Brown	4	11	1	1892	6	43	38	− 0
259	do	Hattiesburg	People's ice factory				1900	6	335		− 0
260	do	do	M. Hemphill				1901	3	350		+ 8
261	do	do	City waterworks				1900	6–4	335	290	+ 30
262	do	do	J. J. Newman Lumber Co.	4	13	11	1899	6	368	368	+ 30
263	do	do	G. L. Hawkins				1898	2	380	375	+ 10
264	do	do	Gulf and Ship Island R. R.				1902	3	350	300	+ 30
265	do	do	Mike Dunn				1902	3	325		+ 0
266	do	Hecla	George Baylis	4	13	10	1897	2	600		+ 0
*267	Pontotoc	Ecru	Mobile, Jackson and Kansas City R. R.				1905	8	93	71	− 0
268	do	McLauren	J. A. Barrow	2	12	4	1897	12	52	48	− 48
269	do	do	R. A. Cooper	8	2	29	1902	6	216	216	+
270	do	do	V. B. Tucker	8	3	31	1898	6	62	62	+
271	do	Sherman	D. C. Longston	8	4	36	1899		250	250	− 40
272	Quitman	Belen	M. E. Denton	28	2	25	1901	2	840	800	+ 0
273	do	do	Turner Bros	28	2	28	1902	3	860	810	+ 0
274	do	do	do	28	1	29	1902	2	724	650	+ 50
275	do	Lambert	Quitman Developing Co.	27	1	22	1904	2	720	680	+ 30
276	do	do	Quitman County Developing Co.	27	1	15	1904	2	690	560	+ 10
277	do	do	Bacon Nolan Co	26	1	15	1904	2½	700	650	+ 40
*278	do	Riverside	L. Marks	28	1	35	1901	2	636	600	+ 40
279	do	Sumner	Bell & Lawrence	25	1	10	1904	2	650	600	+ 30
280	Scott	Forest	O. B. Triplett	6	8	16	1896	3	220	220	− 9
*281	Smith	Taylorsville	Thomas James	10	14	17	1902	6	1,135	1,100	+ 0

* See text, pp. 36–38, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
Flows	Soft	5	None apparent	Lowered	Selma	Tuscaloosa	*249
Pump	do		Little	Lowers 16 feet	do	do	*250
do	Alkaline, soft.		None apparent	Little	do	do	*251
					do	do	252
Compressed air.	Soft	145	None apparent	Slight	do	do	*253
do	Soft, alkaline.	145	Neither	do	do	do	*254
Flows	Hard	60	None apparent		Port Hudson.	Wilcox	*255
do	do	50			do	do	256
Bucket	do				Lafayette	Lafayette	*257
	do	100			do	Grand Gulf	*258
Bucket	Soft		None apparent		Second river bottom.	do	259
Flows	do	Few	do		Lafayette	do	260
do	do	250	None	Slight	Second river bottom.	do	261
do	Hard	250	Small decrease		do	do	262
do	Soft	Few	None apparent		Lafayette	do	263
do	do	150	do		Second river bottom.	do	264
do	do		None		do	do	265
do	Hard	100			Lafayette	do	266
Bucket	do				do	do	*267
Cook-pump	Soft	120	Decreased	Lowered 3 feet in 6 hours.	Ripley	Ripley	268
Flows	do	20			Lafayette	do	269
do	Hard	1½			Ripley	do	270
Pump					Lafayette	do	271
	Soft	20	Decreased		Alluvium	do	272
Flows	do	60	None apparent		Port Hudson.	Wilcox	273
do	do	55	do		do	do	274
do	do	52	Neither		do	do	275
do	do	60	Increased		do	do	276
do	do	100	do		do	do	277
do	do	60	None apparent		do	do	*278
do	do	40	Same		do	do	279
		10			Lafayette	Jackson	280
Flows		6			do	Grand Gulf	*281

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Range.	Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	*Feet.*	*Feet.*	*Feet.*
282	Sunflower....	Belmont......	State................	....	....	....	......	....	1,000	1,000	+
*283	.....do........	Dockery......	Will Dockery........	22	4	33	1901	2½	929	929	+35
284	.....do........	Doddsville....	R. E. Dodds........	21	3	29	1900	2	820	820	+70
285	.....do........	Indianola.....	City................	....	....	....	1904	4	1,320	......	+49
286	.....do........	.....do........	W. B. Martin........	19	4	31	1900	3	1,300	1,260	+
*287	.....do........	Moorhead	Chester H. Pond....	18	3	4	1899	2	936	936	+45
288	.....do........	Ruleville......	Chas. Campbell.....	22	3	31	1900	3	864	820	+
289	.....do........	.....do........	Rule Bros...........	22	3	31	1900	2	865	700	+70
290	.....do........	Sunflower....	R. C. Burroughs....	19	3	5	1889	1½	880	880	+
291	Tallahatchie..	Albin.........	Jerry Robinson.....	24	1	29	1900	3	517	......	+
292	.....do........	Charleston....	J. W. Saunders.....	25	2	26	1901	2½	760	545	+18
293	.....do........	.....do........	M. P. Webb.........	24	2	15	1901	2	420	420	+
294	.....do........	.....do........	W. G. Harvey.......	....	....	....	......	....	450	450	+10
295	.....do........	Crevi.........	C. W. Neilson.......	26	2	10	1902	2	400	380	+
296	.....do........	Glendora.....	E. D. Graham.......	23	12	28	1898	2	465	420	+
297	.....do........	Sharkey Landing.	T. G. James.........	24	1	35	1899	3	450	390	+
298	.....do........	Sumner.......	I. B. Dudley........	24	2	11	1901	2	552	......	+
299	.....do........	Swanlake.....	W. A. Hawkins.....	23	1	10	1901	2	582	......	+
300	.....do........	Webb.........	E. B. Taylor........	24	1	18	1899	2	512	480	+
*301	Tate..........	Staghorn.....	S. T. Clayton.......	5	9	21	1901	30	110	107	−
302	Tippah.......	Dumas........	A. C. Anderson.....	4	5	13	1901	40	60	55	−55
*303	Tunica.......	Tunica.......	City................	....	....	....	......	....	865	865	+ 0
304	.....do........	Commerce....	R. F. Abbey........	4	11	32	1900	2½	865	......	+
*305	.....do........	Longtown....	....	....	....	....	......	2	521	471	+
*306	Union........	New Albany..	City................	....	....	....	......	....	230	230	+40
*307	Washington..	Leland.......	.....do..............	18	7	15	1900	6	512	452	−14
308	Wayne.......	Red Bluff.....	.....do..............	....	....	....	1900	3½	265	......	+ 5
*309	.....do........	Waynesboro..	.....do..............	8	7	12	1900	4	525	......	+10
310	.....do........	.....do........	Ice factory..........	8	7	12	1902	4	520	......	+10
311	.....do........	.....do........	Turpentine distillery	8	7	12	1902	4	525	......	+10
312	Webster......	Walthall......	J. L. Lamb..........	21	10	30	1898	6	......	......	+20
313	Winston......	Louisville.....	W. C. Hight.........	15	12	27	1870	36	42	32	−32
314	Yalobusha....	Coffeeville....	J. A. Aston..........	....	....	....	1901	2	250	230	+ 1½
*315	.....do........	.....do........	W. C. Bryant.......	24	6	28	1903	2	238	238	+10
316	.....do........	.....do........	W. H. Bailey.......	24	6	4	1899	2	160	145	+12
317	.....do........	.....do........	J. F. Proovin.......	24	6	....	1901	2	275	250	+ 5
*318	.....do........	Water Valley.	City................	11	4	5	1897	6	60	40	−12
*319	Yazoo........	Yazoo........	.....do..............	....	....	....	1905	6	1,577	......	......
320	.....do........	Sartartia.....	M. King............	10	3	31	1898	3	588	588	+

* See text, pp. 38-39, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing statum.	No.
		Gals.					
Flows		250			Port Hudson.	Claiborne	282
do		80			do	do	*283
do		80			do	do	284
do		200			do	do	285
do	Alkali	20			do	do	286
do		20			do	do	*287
do		100	Neither		do	Wilcox	288
do		75	do		do	do	289
do		50			do	do	290
do		25			do	do	291
do		32			do	do	292
do		50			do	do	293
do		25			do	do	294
do		40			do	do	295
do		60			do	do	296
do		50			do	do	297
do		12			do	do	298
do		75			do	do	299
do		75			do	do	300
Windlass					Lafayette	do	*301
Bucket					do	Ripley	302
Flows	Soft	200	Neither		Port Hudson.	Wilcox	*303
do	do		do		do	do	304
do	do	3	do		do	do	*305
do		15			do		*306
Pump	Soft		Same	None	Port Hudson.	Claiborne	*307
Flows	do		do		Vicksburg	do	308
do	do	25	do		do	do	*309
do	do	20-40	Variable		do	do	310
do	do	25	None apparent		do	do	311
do		60			Lafayette	Wilcox	312
Bucket					do	do	313
Flows		$1\frac{1}{2}$			do	do	314
do		25			do	do	*315
do					do	do	316
do		2			do	do	317
Steam pump					do	do	*318
		14			Alluvium	Claiborne	*319
					Port Hudson.	do	320

SELECTED RECORDS IN DETAIL.

[Numbers in heavy-faced type refer to preceding table.]

10. *Record of city wells at Corinth, Alcorn County.*

[Authority, city waterworks.]

		Feet.
Common soil		15
Blue clay	Selma chalk	20
Sand	Selma chalk	30
Hard rock	Selma chalk	1
Sand, water bearing		35
Hard shale, clay, and fine sand, Eutaw-Tuscaloosa		200
Sandstone, limestone, and shale (Chester and St. Louis)		135
Siliceous rock ("flint rock"), Tullahoma		115

12. *Record of city well at Kosciusko, Attala County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay and sand	30	30
Black clay	10	40
Black clay and rock	25	65
Rock, greensand, and shells	25	90
Sand and shells	60	150
Black dirt (lignite)	50	155
Gray sand	40	195
Black clay and gray sand	50	245
Gray sand, black clay, and rock	30	275
Water-bearing sand	5	280

Water is found at 35 feet, 75 feet, 195 feet, and 275 feet. Water rises to 75 feet of surface.

Record of shallow well in sec. 36, T. 20, R. 8 W., Bolivar County.

[Authority, unpublished notes of E. A. Smith, assistant geologist of Mississippi, 1870.]

	Thickness (feet).	Depth (feet).
Surface loam	3	3
Sand, as seen freshly deposited by Mississippi River	3	6
Black buckshot clay	30	36
Red clay, source of water		36

The above is an open dug well. As soon as the red water-bearing clay was reached the water rushed in so rapidly that the digger had hardly time to get out before the well was filled. Water rises to within 15 feet of the surface.

Record of well in sec. 19, T. 19, R. 5 E., Carroll County.

[Authority, unpublished notes of E. A. Smith, assistant geologist of Mississippi, 1870.]

	Thickness (feet).	Depth (feet).
Surface soil.		
Variegated clay	16	16
Indurated ledge of ferruginous sand, with seams of crystalline salenite alternating with layers of greensand	4	20
Greensand	9	29
Indurated ledge of ferruginous sand alternating with layers of greensand, as above	4	33
Hard rock, which effervesced in places	3	36
Siliceous, indurated greensand, with shells	6	42
Light-yellow sand, with ledges of indurated sand, containing concretions of sandstone, also clay nodules embedded in the sand	6	48

Strong mineral water was obtained at 44 feet.

20a. *Record of railroad well at Okolona, Chickasaw County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil, gravel, and clay	20	20
Blue limestone (Selma chalk)	300	320
Hard sand rock	3	323
Sand rock	100	423
Greensand, soapstone, and water	50	473
Soapstone	75	548

Water rises within 22 feet of surface.

21a. *Record of well at Hermanville, Claiborne County.*

[Authority, W. G. Herrington, driller.]

	Total depth (feet).
Red clay	86
Gray clay	
Sand rock	
Hard blue clay (hardpan)	
Fine blue sand, which supplies abundant water	

25. *Record of town well at Enterprise, Clarke County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Sand	6	6
Clay and sand	10	16
Quicksand	6	22
Hard blue rock	½	22½
Blue soapstone	97½	120
White sand and blue rock	25	145
Soft soapstone	7	152
White sand and gravel	4	156

35. *Record of Weems well at Shubuta, Clarke County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Sand and clay	25	25
Marl	125	150
Marl, clay, and sand	272	422

Water flows above surface.

52. *Section of town well at West Point, Clay County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil and loam	20	20
Limestone (Selma chalk)	180	200
Sand and clay	400	600

Water flowed at first, but does not now.

52a. *Record of town well at Cedar Bluffs, Clay County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil and loam	10	10
Limestone (Selma chalk)	450	460
Hard rock	2	462
Sand and water	188	650

Water rises within 100 feet of surface.

Record of well 3 miles south of Grenada, Grenada County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	10	10
Sand	30	40
Soapstone	30	70
Sand	10	80
Soapstone (clay)	10	90
Mud	20	110
Soapstone (clay)	10	120
Very coarse sand	95	215
Hard rock	0.25	215.25
Sand	10	225.25
Soapstone (clay)	335	560.25
Two thin rocks	0.75	561
Soapstone (clay)	40	601
Water-bearing sand	63	664
Soapstone	20	684
Water-bearing sand	37	721

Well flows one-half gallon per minute.

56a. *Record of city well at Grenada, Grenada County.*

	Thickness (feet).	Depth (feet).
Surface loam	60	60
Sand	30	90
Soapstone (clay)	30	120
Sand and soft clay	40	160
Soapstone (clay) with sand	90	250
Blue sand	30	280
Soft stone (clay?)	30	310
Soft blue sandy rock, very fine	140	450
Soft clay	10	460
Sand and water	30	490
Soft blue sandy rock	110	600
Rock	20	620

At a depth of 250 feet water rose within 6 feet of surface; at 490 feet the well overflowed.

Record of well 1 mile north of Bay St. Louis, Hancock County.

[Begun October 29, 1904; completed November 20, 1904. Authority, John L. Ford, driller.]

	Thickness (feet).	Depth (feet).
Blue sandy clay	10	10
White sand	50	60
Yellow sand	35	95
White sand and gravel	50	145
Green clay	15	160
Gray sand	60	220
Green clay	130	350
Gray sand	20	370
Green clay	280	650
Water sand, flows 50 gallons per minute	40	690
Blue clay	128	818
Water sand, flows 225 gallons per minute	79	897

Diameter of well, 3 inches. (From Bull. U. S. Geol. Survey No. 264.)

Generalized section of wells between Biloxi and Pass Christian, Harrison County.

[Authority, A. Dixon.]

	Feet.
Sand	80
Clay	125
Sand and clay	425
Light-gray fine sand	500
Clay	600
Water-bearing sand	685

Record of well at Quarantine Station, Ship Island.

[Authority, Dr. P. C. Kallock in Underground Waters of Louisiana (Harris).]

	Thickness (feet).	Depth (feet).
White sand	45	45
Soft clay and mud	155	200
Hard blue clay	100	300
White sand	5	305
Blue clay	260	565
Sandstone	½	565½
Blue clay	156	721½
Water-bearing sand	9	730½

112. *Record of well at Howison, Harrison County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Red clay	100	100
White sand	100	200
Blue clay	1,200	1,400
Water-bearing sand	80	1,480

Water rises within 35 feet of surface.

Log of deep well at State Penitentiary, Jackson, Hinds County.

[Authority, E. W. Hilgard.]

	Thickness (feet).	Depth (feet).
Surface materials and clay marl	20	20
Blue sandy shell marl	11	31
Dry sand, with streaks of whitish or gray clay containing impressions of leaves	80	111
Wet quicksand, caving very badly	70	181
(Here water rose to within 70 feet of surface.)		
Black clays, mostly laminated, interstratified with layers of sand. Fragments of impressions of leaves, and, at 400 feet, a catkin of a willow were bored up	268	449
Greensand, with shells and streaks of gray and red clay	30	479
Water-bearing sand, caving badly	20	499
(Here water rose to within 50 feet of surface.)		
Greensand with shells, same as above	?	
Ledge of gray fossiliferous limestone	1	500
Blue clay, with calcareous nodules and some layers of greensand marl	12	512
Shell marl, with layers of black clay	10	522
Quicksand, with a great deal of mica	5	527
White indurated clay, with iron pyrites, not yet passed through	?	

Record of Alabama and Vicksburg Railroad well at Smiths, Hinds County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil and clay	44	44
Limestone and sandstone	104	148
Thin strata of hard rock	4	152
Rock and sand	394	546

Water rises within 23 feet of surface; capacity, 113 gallons per minute; mouth of well about 130 feet above sea level.

Generalized section of wells on Deer and Silver creeks, Issaquena County.

[Authority, unpublished notes of E. A. Smith, assistant geologist of Mississippi, 1870–71.]

	Thickness (feet).	Maximum depth (feet).
Top clay	4–10	10
Sand	20–30	40
Blue mud (clay)	10–20	60
Light, fine sand	2–4	64

Pebble bed, containing water.

The above section was given by Mr. I. W. Blessing, who had driven about 70 wells along the above-mentioned creeks. The sand above the pebbles is in very fine, smooth, rounded grains, and comes up with the water when the well is pumped. The pebbles in the bed from which the water comes are often cemented together, forming a hard conglomerate.

167. *Record of well near Moss Point, Jackson County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Sand	100	100
Clay and mud	150	250
Hard clay	150	400
Water-bearing sand	20	420
Hard clay	200	620
Water-bearing sand	40	660
Sand and clay	110	770
Water-bearing sand	44	814
Hard rock, sand, mud, and wood	736	1,550

Flowing water at 650 and at 800 feet.

181. *Record of city well at Scranton, Jackson County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Sand and gravel	350	350
Blue clay	400	750
Clam shells	5	755
Blue clay	25	780
Water-bearing sand	20	800

Well flows 150 gallons per minute.

Record of well at Ocean Springs, Jackson County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Surface soil, sand, and gravel	150	150
Clay	250	400
Sand	20	420
Clay	40	460
Sand and gravel	60	520
Clay	400	920
Water-bearing sand	30	950

Water flows 250 gallons per minute.

Record of well 1½ miles northwest of Moss Point, Jackson County.

[Begun October 3, 1904; completed October 12, 1904. Authority, John L. Ford, driller.]

	Thickness (feet).	Depth (feet).
Hard, yellow clay (sandy)	20	20
Yellow sand	15	35
Clay (sandy, variegated)	15	50
Sand (fine, white)	50	100
Sand (coarse, white)	40	140
Clay (sandy)	70	210
Sand (fine, white)	10	220
Clay	150	370
Sand (fine, white)	20	390
Clay	320	710
Sand (fine, gray)	80	790
Clay		790

Main water supply 770 to 790 feet. Yield, 135 gallons per minute. (From Bull. U. S. Geol. Survey No. 264.)

Record of city well at Ellisville, Jones County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Sand and gravel	80	80
Green clay	280	360
Sand	10	370
Green clay	230	600
Sand rock	12	612
Greenish marl	288	900
Shell rock	5	905
Green marl	195	1,100
Shells	5	1,105
Green marl	295	1,400

Record of city well at Oxford, Lafayette County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay and sand	90	90
Dry sand	15	105
Clay	67	172
Soapstone (clay)	78	250
Hard sandstone	50	300

Water rises to 70 feet of surface.

Record of well at Lumberton, Lamar County.

[Authority, W. N. Logan and W. R. Perkins.]

	Depth (feet).
Coarse sand and some gravel	40
Fine sand	85-90
Fine sand and white clay	103
Hard white clay	110
Soft but fine sand	180
Hard white clay	200
Hard and soft spots, water white	210
Hard white clay, pipe goes 28 inches per hour	277
White water	314
Blue mud	512-528
Blue mud, still in water	560
Hard clay, white water	620
Very soft rock	670
Very soft white clay	682
Hard clay	720
Blue clay	760
Hard rock	770
Softer rock	784
Bluish rock	830
Hard rock	850
Sand	860

The well was drilled to a depth of 1,800 feet.

Record of cotton-mill well No. 1, Meridian, Lauderdale County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	14	14
Sand	16	30
Clay	6	36
Shale	14	50
Sand	1	51
Lignite	2	53
Sand	3	56
Shale	2	58
Pipe clay	19	77
Lignite	6	83
Pipe clay	7	90
Sand	2	92
Clay	3	95
Sand	4	99
Clay	22	121
Sand	5	126
Clay	5	131
Sand	5	136
Blue clay	4	140
Sand	1	141
Blue clay	18	159
Sand	9	168
Lignite	5	173
Sand	2	175
Lignite	4	179
Sandstone	1	180
Clay	7	187
Sand	27	214
Lignite and clay	8	222
Clay	2	224
Sand	2	226
Lignite	2	228
Sand	27	255
Clay	12	267
Lignite	4	271
Clay	27	298
Sand	4	302
Clay	4	306
Sand	6	312
Clay	5	317
Pyrites rock	1	318
Sand	3	321
Clay	7	330
Lignite	2	332
Clay	15	347
Sand	43	390

Water rises within 40 feet of surface.

Record of well in sec. 11, T. 9, R. 8 E., Leake County.

[Authority, unpublished notes of E. A. Smith, assistant geologist of Mississippi, 1871.]

	Thickness (feet).	Depth (feet).
Red clay, with a little sand	6	6
Variegated clays, containing shells	10	16
Light-colored, fossiliferous rock which effervesces with hydrochloric acid	1	17
Variegated clays, as above	9	26
Yellow sand to water	26	52

Record of well at Mooresville, Lee County.

	Thickness (feet).	Depth (feet).
Selma chalk	155	155
Eutaw sands, source of water	20	175

205a. *Record of Brick and Tile Company's well at Baldwyn, Lee County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil, clay, and sand	40	40
Limestone (Selma chalk)	74	114
Clay and sand (Eutaw)	220	334
Water-bearing sand	46	380

Water rises within 5 feet of surface.

212b. *Record of Mobile and Ohio Railroad well, Tupelo, Lee County.*

[Authority, M. & O. R. R. Co.]

	Thickness (feet.)	Depth (feet).
Sand and gravel	15	15
Limestone } Selma chalk	200	215
Hard rock } Selma chalk	1	216
Soft rock } Selma chalk	150	366
Greensand, water-bearing	40	406
Clay	30	436

Water flows above surface.

Record of T. B. Minyard's well, at Greenwood, Leflore County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil and clay	15	15
Mud and silt	140	155
Soapstone (clay)	200	355
Greensand, with the strata of hard rock	20	375

221a. *Record of well at Minter City, Leflore County.*

[Authority, C. E. Feigler, driller.]

	Thickness (feet).	Depth (feet).
Surface soil	10	10
Sand	100	110
Gravel	10	120
Sand	80	200
Soapstone and pipe clay interbedded with sand to bottom of well	237	437

225a. *Record of railroad well at Columbus, Lowndes County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay, sand, and gravel	25	25
Sandstone	300	325
Greensand and clay	95	420

225b. *Record of railroad well at Artesia, Lowndes County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	10	10
Limestone (Selma chalk)	350	360
Hard sandstone	2	362
Soft sandstone and soapstone	175	537
Clay and sand	60	597

Water rises to within 18 feet of surface.

Record of well at Canton, Madison County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Surface sand and clay	150	150
Clay	175	325
Water-bearing sand	30	355
Clay	60	415
Water-bearing sand	30	445

Record of well in sec. 2, T. 7, R. 2 E., Madison County.

[Authority, E. W. Hilgard.]

	Thickness (feet).	Depth (feet).
Surface materials and bluish and yellowish clay marls	40	40
Blue clay marl, poor in shells	40	80
Blue sandy shell marl, with well-preserved shells	10	90
Dark-colored, mostly bluish, laminated clays interstratified with layers of sand	185	275
Hard gray sandstone	$\frac{1}{12}$	
Yellow water-bearing sand	15	290
(Here water rose to within 75 feet of surface.)		
Dark-colored sandy clay, with crystals of gypsum	85	375
Hard gray sandstone	$\frac{1}{12}$	
Lignite, interstratified with layers of clay; above it a stream of water rising to within		375
45 feet of surface (as far as penetrated)	40	415

230. *Record of town well at Holly Springs, Marshall County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Reddish clay (Columbia)	20	20
Red sand (Lafayette)	87	107
Sand rock	1	108
Clay	52	160
Hard sandstone	½	160½
Clay and sandstone	139½	300
Fine sand, water bearing	40	340
Pipe clay	13	353
Coarse sand	4	357
Sticky clay	43	400

General section of wells in river bottom near Aberdeen, Monroe County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Surface soil and loam	15	15
Sandstone	200	215
Sand and first water	35	250
Clay and lignite	100	350
Sand and water	30	380

232a. *Record of well at Amory, Monroe County.*

[Authority, A. F. Crider; section obtained from old well driller.]

	Thickness (feet).	Depth (feet).
Lafayette sand	12	12
Lafayette gravel	6	18
Gray sand, water bearing	1	19
"Soapstone," or joint clay, with thin layers of shelly sandstone. The clay caved when drilling well and had to be cased	115	134
More compact clay, which required no casing in drilling	65	199
Sand, source of water.		

Water was obtained in sand below the compact clay. It flows at rate of 20 to 25 gallons per minute from a 2½-inch pipe. The water is highly impregnated with iron oxide. The pipe and gutter which carry the water from the well are covered with a thick coating of iron oxide. The same driller reports that a second stream of water is present here at a depth of from 240 to 250 feet.

Well at Gattman, Monroe County.

[Authority, W. F. Riley, owner.]

	Thickness (feet).	Depth (feet).
Sandy yellow clay	18	18
Fine sand (quicksand)	65	83
Gravel and sand	4	87
Yellow sand Gray sand Blue clay Deep-red clay Lignitic clay Sand	113	300
Hard grayish sand rock	2	302
Fine sand or opening from which water rose to surface, furnishing about 2 gallons per minute	6	308
Small, round gravel, about the size of large shot	3	311
Hard gray sandstone (hard as millstone), becoming softer and darker in color below. Water rose to surface from this soft sandstone	312	623

Water flows above surface at the rate of 15 gallons per minute, is full of gas bubbles, and has a taste of borax and soda.

235. *Record of well at Winona, Montgomery County.*

[Authority, Robert A. Allison.]

	Thickness (feet).	Depth (feet).
Soil and clay	25	25
Orange-colored sand	10	35
Blue marl	40	75
Lignite	5	80
Quicksand	15	95
Black clay	50	145
Coarse sand, containing fair supply of water	10	155
Lignite	10	165
Blue marl	35	200
Fine sand	15	215
Clay	10	225
Quicksand	60	285
Clay	40	325
Fine sand, coarse on top	25	350
Brown clay	35	385
Coarse sand, gravels on top	27	412

Water is obtained in the lowest layer of coarse sand and gravel at a depth of 395 feet. About 25 or 30 wagonloads of sand were pumped from the well during the first three or four days. After that the sand ceased to rise, and the well now furnishes an abundant supply of water, which is not perceptibly lowered with an air-lift pump. Water is clear and free from minerals, and is reported to have a temperature of 65° F.

244b. *Record of railroad well at Brookville, Noxubee County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	8	8
Limestone (Selma chalk)	450	458
Hard sand	4	462
Soft sand	150	612
Greensand and water	45	657

The water rises within 60 feet of surface.

245. *Record of well at Cliftonville, Noxubee County.*

[Authority, J. B. Cunningham, driller.]

	Thickness (feet).	Depth (feet).
Selma chalk	300	300
Greensand	20	320
White sand	20	340
Greensand	10	350
White sand	40	390
Ferruginous sandstone	1	391
Dark greensand, source of water	60	451

246. *Record of well at Ravine, Noxubee County.*

[Authority, J. B. Cunningham, driller.]

	Thickness (feet).	Depth (feet).
Selma chalk	250	250
Greenish-colored sand (Eutaw)	475	725

249. *Record of Mobile and Ohio Railroad well, Macon, Noxubee County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	8	8
Limestone (Selma chalk)	600	608
Hard sandstone	3	611
Soft sandstone	65	676
Greensand and water	40	716
Soapstone	53	769

251. *Record of Shuqualak well, Noxubee County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	10	10
Limestone (Selma chalk)	750	760
Sandstone	100	860
Greensand and water	50	910

Water rises within 10 feet of surface.

254. *Record of well at Starkville, Oktibbeha County.*

[Authority, Bulletin of the Mississippi Agricultural and Mechanical College, vol. 1, No. 2, page 10.]

	Thicknes (feet).	Depth (feet).
Surface soil	14	14
Selma chalk	749	763
Shell rock	4	767
Clay (sandy)	24½	791½
Shell rock	7	879½
Sand (micaceous)	56	854½
Clay	10	864½
Sand	35½	900

Water rises within 150 feet of the surface.

255. *Record of town well at Batesville, Panola County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Surface	10	10
White sand	25	35
Blue clay	10	45
Clay and sand	215	260
Rock	2	262
Water-bearing sand	40	302

Water rises 20 feet above the surface; flows 50 gallons per minute.

257. *Record of well at Barbara, Perry County.*

[Authority, A. J. Thomas, owner.]

	Thickness (feet).	Depth (feet).
Red surface clay	40	40
Coarse sand and sandstone	2	42
Blue pipe clay	7	49
Yellow sand	13	62
White sand and sandstone	10	72

General section of wells at Hattiesburg, Perry County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Pinkish clay	100	100
Water and sand	30	130
Greenish clay	150	280
Water-bearing sand and gravel	20	300

There are about 25 wells in the town flowing from 5 to 50 gallons per minute.

258. *Record of well at Brown, Perry County.*

[Authority, A. G. Brown, owner.]

	Thickness (feet).	Depth (feet).
Red clay	20	20
Variegated sand, of white, red, and yellow color, with occasional thin layers of "rock"	23	43

Water obtained at 38 feet.

267. *Record of well at Ecru, Pontotoc County.*

[Authority, Albert Goldsbury, driller.]

	Thickness (feet).	Depth (feet).
Red clay and loam	23	23
Blue clay	27	50
Hard limestone	4	54
Reddish muddy sand	5	59
Shell marl	1	60
Sand	3	63
Reddish sand, water-bearing	10	73
Gray clay to bottom of well	20	93

Diameter of well, 6 inches. Water barely flows over surface, and is raised to tank by steam pump. It is clear, and is used in locomotive boilers.

278. *Record of L. Marks's well at Riverside, Quitman County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Blue mud	40	40
Mud and water-bearing sand	45	85
Water-bearing sand and gravel	50	135
Sand and gravel	40	175
Soapstone (clay)	220	395
Rock	½	395½
Soapstone (clay)	50	445½
Rock	½	446
Greensand	10	456
Lignite	1	457
Soapstone (clay) and water-bearing sand	179	636

Record of town well at Forest, Scott County.

[Authority W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Mud and gumbo	60	60
Black mud	15	75
Grayish sandy clay	25	100
Gray sand and iron pebbles	50	150
Lime rock	40	190
Sandy rock	5	195
Dark-gray hard rock	22	217
Water-bearing sand	2	219

Water rises within 90 feet of surface.

Record of well in sec. 8, T. 10, R. 7 W., Sharkey County.

[Authority, unpublished notes of E. A Smith, assistant geologist of Mississippi, 1870.]

	Thickness (feet).	Depth (feet).
Sandy loam; Dark, sticky clay	20	20
Buckshot clay	10	30
Fine, sticky, sandy clay, containing water		30

281. *Record of well at Taylorsville, Smith County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Grayish-brown clay	100	100
Blue clay	200	300
Sand, gravel, and water	15	315
Brownish clay	85	400
Hard rock	23	423
Sand	3	426
Brownish clay	704	1,130
Brown sand, very fine	5	1,135

Water flows 10 gallons per minute.

283. *Record of well at Dockery, Sunflower County.*

[Authority, Will Dockery, owner.]

	Thickness (feet).	Depth (feet).
White sand	60	60
Gravel and sand	115	175
Quicksand with strata of clay about 50 feet apart; flowing water	600	775
Sand rock in layers 18 inches to 2 feet thick interbedded with sand	25	800
Greensand interbedded with rock	129	929

294. *Record of well at Charleston, Tallahatchie County.*

[Authority, W. G. Harvey, owner.]

	Thickness (feet).	Depth (feet).
Sands, silts, and clays	200	200
Sandstone rock	10	210
Lignite and lignitic clays	140	350
Quicksand	100	450

Water rises 8 to 10 feet above the surface. Capacity, 25 gallons per minute.

Record of town well at Charleston, Tallahatchie County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay and blue mud	50	50
Sand	40	90
Soapstone (clay)	100	190
Hard white rock	2	192
Water-bearing sand	100	292
Soapstone (clay)	30	322
Water-bearing sand	40	362

Well flows 32 gallons per minute.

301. *Record of well at Staghorn, Tate County.*

[Authority, S. T. Clayton, owner.]

	Thickness (feet).	Depth (feet).
Surface clay	20	20
Gravel and sand	15	35
Red sand which changes to white sand; Pipe clay and sand, furnishing water	75	110

Water rises but a few feet in the well.

Record of well at Senatobia, Tate County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	24	24
Coarse gravel	15	39
Quicksand	21	60
Clay	4	64
Sand	10	74
White clay	2	76
Sand	14	90
Pipe clay	2	92
Water-bearing sand	28	120

Water stands within 40 feet of the surface.

303. *Record of well at Tunica, Tunica County.*

[Authority, W. J. Brigham.]

	Thickness (feet).	Depth (feet).
Alluvial sand and clay	15	15
Fine silt, sand, and clay	75	90
Fine white sand	250	340
Sand and gravel with layers of lignite Sand Hard, impervious clay White sand containing water	525	865

Water is soft and flows above surface.

305. *Record of well 5 miles west of Longtown, Tunica County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil and clay	30	30
Sand	110	140
Pipe clay	260	400
Rock	1	401
Sand	10	411
Soapstone (clay)	60	471
Sand and water	50	521

Water flows 15 gallons per minute.

306. *Record of well at New Albany, Union County.*

[Authority, Ed. Baker, driller.]

	Thickness (feet).	Depth (feet).
Surface clay	20	20
Calcareous sandstone	4	24
Clayey sand, water bearing	15	39
Blue sandy marl containing shells, with strata of limestone 3 to 4 feet thick at occasional intervals	165	204
White sand, source of water	20	224

307. *Record of city well at Leland, Washington County.*

[Authority, E. F. Turner, chairman of water committee.]

	Thickness (feet).	Depth (feet).
Buckshot clay	2	2
Fine sand	138	140
Gravel	14	154
Hard blue clay, containing six strata of sandstone rock, ranging in thickness from 6 inches to 2 feet	298	452
Coarse gray sand	60	512

Analysis of the above water is reported to have given 154.1 parts per million of solid matter, 119.8 of which were soda.

309. *Record of town well at Waynesboro, Wayne County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Surface clay	30	30
Sand and water	150	180
Marl and clay with flint "bowlders"	300	480
Water-bearing sand	20	500
Clay	25	525

Water flowed above surface from 180 feet.

318. *Record of well at Water Valley, Yalobusha County.*

[Authority, R. F. Kimmons, mayor.]

	Thickness (feet).	Depth (feet).
Common surface clay	12	12
Water-bearing sand	15	27
Stiff pipe clay	18	45
Water-bearing sand	15	60

The city of Water Valley has nine wells similar to the above, which furnish 500,000 gallons of water per day. Water stands within 12 feet of the surface. Six of the wells have furnished the above amount of water without any appreciable variation. All the wells are dug within a radius of 100 feet.

Record of well in sec. 23, T. 14, R. 4 W., Yazoo County.

[Authority, unpublished notes of E. A. Smith, assistant geologist of Mississippi, 1870.]

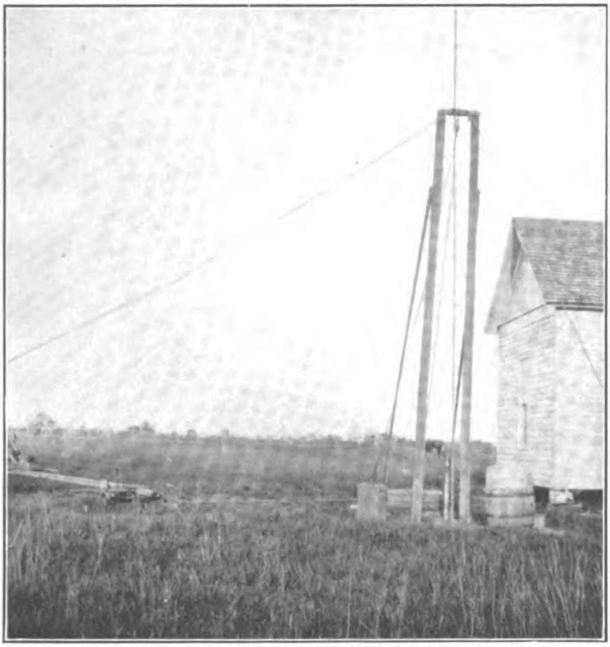
	Thickness (feet).	Depth (feet).
Surface soil	2½	2½
Red clay	6	8½
Buckshot clay Blue mud	21½	30

Water is warm and has slight mineral taste.

SANITARY ASPECT OF WELLS.

There is a widespread popular belief that clear, cold water coming from any kind of well is pure and wholesome, and until recent years the open well has been considered one of the most valuable adjuncts of the home or farm. In reality, however, wells of the open type are especially liable to pollution and may be the source of disease. On many premises the open well is in the lowest ground, and above it on the slopes are barns, outhouses, and dwellings. Such a case is illustrated in Pl. VI, *B*. The lowest ground is chosen for the well because water is found there at less depth than elsewhere. The fact that the impurities from the sources mentioned are carried both by the surface water after each rain and by underground seepage downward in the direction of the well is commonly lost sight of. Water laden with impurities may either enter the top of the well, where this is unprotected by embankments, or it may enter through the wood, brick, or stone curbing. The pollution of the well by seepage is especially likely to occur where the soil is porous and the well shallow, and, in limestone regions, where open underground channels exist.

It is not infrequently the case that open wells are left uncovered, so that impurities carried by the winds are free to settle through the open mouth. Where covered, the top of the well is often but little above the ground level, and the covering is made of unjointed planks loosely thrown down and having large openings between them. Wooden curbs, which in dry weather shrink and later admit much surface water to the well, are in common use. Chickens and pigs tramping around the barnyard and open privies and workmen from the barnyard or manured fields often carry filth on their feet. The first shower of rain or the drippings from the well bucket may carry these poisonous germs into the well. There are numerous instances in Mississippi where little cesspools have been dug in the ground near the wells and are kept filled with water for chickens, ducks, turkeys, and pigs. This water becomes highly polluted and more or less of it sinks into the earth and finds its way directly into the well.



A. OUTFIT FOR DRIVING TUBULAR WELLS.

Such wells are ordinarily safe, as the shallow polluted waters are shut off.

B. A COMMON BUT HIGHLY DANGEROUS WELL LOCATION NEAR BARNS AND OUTHOUSES.

Drainage is toward well. Photograph by M. L. Fuller.

When in health the human body is resistant to disease, and polluted waters may be used for years without causing sickness; if, however, the human system for any reason becomes weakened, disease germs, if present, may rapidly develop. Many outbreaks of typhoid fever, both in this country and in Europe, have been traced to polluted wells or to milk distributed in cans washed in the water from them.

The well, if used for drinking water, should occupy a high point on the premises and should be so situated that polluted waters from any source can not run near it. If the well is an open one the upper part should be dome-like in shape and sealed with cement, with a tightly fitting top, so that no impurities of any kind can get in.

Many who are accustomed to the open well have a prejudice against drinking water from an iron pump. The driven, bored, and drilled wells have, however, many advantages over the large dug wells, some of which are as follows:

1. There is less possibility of getting impurities into small-bore wells put down with machinery.

2. There is always a possibility that rats, frogs, and other objectionable animals or matter, such as filth from the barnyard, will get into an open well if the cover is left off in some unguarded moment. The well of small diameter which has a pump in it is sealed from all small animals, bugs, and even dust. A few strokes of the pump will remove the water which has been standing in the pipe and bring up water which is fresh and uncontaminated.

3. The well of small diameter, when properly made, shuts off all surface waters and objectionable seepage waters. If a good supply is found, all the objectionable waters above and below should be cased off, so that only the desirable supply is admitted into the pipe.

The so-called "streams" of water in Mississippi and the entire Gulf embayment area occur in horizontal sheets of sand. These water-bearing sands are usually overlain by layers of clay which prevent the waters immediately above the clay from entering the sands below. Where this tough clay layer is penetrated by the drill the water from above will flow down to the bottom of the well unless it is shut off. But when iron casing is put in, packing can be placed between the outside of the pipe and the clay layer, thus sealing up the hole made by the drill and shutting off undesirable waters.

4. It is not possible to dig wells by hand to a very great depth, and in some instances, as in some localities in the Northeast Prairie and in the Yazoo Delta, it is impossible to dig them to the desired source of water without putting in some kind of curbing. In the various artesian basins over the State artesian wells are obtained only by drilling or boring.

If water runs through a sufficient amount of pure sand it will give up a considerable part of its impurities. A large part of the surface of Mississippi is made up of such sand, which serves as a natural filter for the waters. In the more hilly sections of the State this sand contains such a small amount of decayed organic matter that waters even from the shallow wells in the Lafayette sands rarely show a trace of organic matter. The shallow wells very seldom have any strong undesirable minerals in their waters, so that such wells in the rural hilly districts of the State furnish, as a rule, excellent drinking water.

Conditions are different in the Yazoo Delta and in the Northeast and Central prairies. The delta is a low, recently formed land, made up of sands and clays containing a large amount of decayed vegetation. The soil is very fertile and produces a vigorous growth of succulent plants, many of which grow up and decay in a year. Large quantities of free ammonia, albuminoids, nitrates, and nitrites are thus set free, part of which are carried down into the soil and thus come in contact with the waters, which rise within a few feet of the surface.

In the Northeast and Central prairies much of the surface sand has been removed, leaving a limestone-clay soil, which as a rule is barren of water.

ANALYSES.

Analyses of Mississippi waters, in parts per million.

DEEP WELLS.

Locality.	Name of well.	Sodium (Na).	Potassium (K).	Calcium (Ca).	Magnesium (Mg).	Sulphate radical (SO_4).	Chlorine (Cl).	Carbonate radical (CO_3).	Phosphate radical (PO_4).	Silica (SiO_2).	Iron and alumina ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Organic matter.	Authority.[a]
Aberdeen	Aberdeen	12.1	5.96	6.28	2.38	1.80	6.11	29.3	....	11.9	18	....	....	A, p. 31.
Ackerman	Kramer	31.7	4.94	11.3	8.15	2.32	6.08	75.7	1.24	28.9	13.5	....	....	A, p. 110.
Agricultural college	College	222	4.73	5.22	.473	3.21	125	388	....	3.39	....	0.694	....	A, p. 42.
Do	Muldrow's	291	13.6	8.28	4.49	1.17	175	505	....	11.9	....	1.38	....	A, p. 43.
Amory	Amory	7.12	4.25	3.71	1.86	3.57	4.21	16.9	....	8.38	11.1	....	....	A, p. 30.
Artesia	Railroad	232	7.66	8.44	1.96	.904	6.85	319	....	16.4	1.99	....	....	A, p. 37.
Batesville	Batesville	5.98	3.45	2.71	2.48	4.72	5.46	13.1	....	29.9	17.2	....	....	A, p. 99.
Biloxi	Well No. 1	56.1	.942	.535	.140	7.18	5.88	65.5	[b] 1.46	41	.748	....	....	A, p. 73.
Do	Waterworks	116	1.23	1.32	.259	4	2.82	....	[b] 1.34	24	.798	....	....	A, p. 74.
Bolton	....	121	7.2	19	5	55	35	140	....	27	12	....	39	B.
Brookhaven	Brookhaven	14.4	5.49	3.78	.939	2.28	....	6.25	....	11.7	.698	....	....	A, p. 67.
Canton	Waterworks	37.4	3.31	6.21	1.56	11.3	6.32	52	....	56.1	1.14	....	....	A, p. 111.
Clarksdale	Well No. 1	161	3.05	.926	.325	1.13	44.6	176	[b] 2.81	38.7	1.30	....	....	A, p. 82.
Do	Well No. 2	112	4.12	41.5	18.2	1.14	19.6	237	[b] .121	16.7	1.65	....	....	A, p. 83.
Do	Well No. 3	8.98	2.73	45.4	29.5	2.18	6.83	148	[b] 1.27	30.6	5.93	....	....	A, p. 84.
Cleveland	Cleveland	254	3.73	1.07	.481	1.17	....	331	[b] 6.92	18.1	6.99	....	....	Do.
Cliftonville	Cliftonville	64.6	1.60	1.43	.270	1.47	68.9	81.4	[b] 1.92	.204	1.75	....	....	A, p. 47.
Columbia	Columbia	12.7	4.64	4.17	.952	18	5.99	....	[b] .534	38.3	1.20	....	....	A, p. 64.
Columbus	Main street	7.85	6.63	10.4	3.77	.101	3.79	37.5	....	9.40	14.2	....	....	A, p. 35.
Do	Kaye	11.1	9.27	7.77	2.62	.534	8.84	29.6	....	10.3	3.34	....	....	Do.
Do	Ice factory	11.8	7.21	9.13	3.10	.431	4.63	38.1	....	9.88	9.08	....	....	A, p. 36.
Crawford	Crawford	249	11.3	10.2	3.87	13	135	227	....	18.9	2.59	....	....	A, p. 38.
Dockery	....	185	13	2.9	1.40	1.2	14.5	237	6.7	25	.9	....	....	C.
Doddsville	Doddsville	192	6.48	2.53	.497	3.57	3.79	254	([b])	20.6	2.49	....	....	A, p. 87.
Durant	....	46	....	65	6.6	54	39	106	([b])	20	....	....	....	D.
Do	Durant, I. C. R. R. Co.	73.6	12.2	4.92	7.93	25.6	11.8	107	.339	25.6	.597	....	....	A, p. 103.

Enterprise	Town	107	12.6	2.64	.721	4.70	3.79	148	[b] 1.23	14.3	.748			A, p. 56.
Glendora	Sturdivant	122	1.96	1.11	.551	2.05	18.2	147	[b] 3.62	30.1	.847			A, p. 91.
Greenville	Greenville	123	2.68	.606	.505	1.85	32.4	135	[b] 2.14	24.9	.397			A, p. 93.
Greenwood		55		2.2	.63	5	3.5	70	([b])	34	2.9			D.
Do	McNeal	30.7	9.32	16.2	4.51	4.23	7.48	73.5		27.8	1.93			A, p. 93.
Do	City	36.8	6.40	10.6	3.01	2.18	4.19	71.4		31.3	.798			A, p. 94.
Grenada (depth 620 feet.).		166	4.3	3.7	1.5	1.2	90	150	3	11	1			
Gulfport	Railroad	49.6	3.93	1.28	.217	9.97	5.88	58.9	[b] 1.34	20.8	.399			A, p. 72.
Do	Pier	69.4	1.53	.963	.194	7.18	5.88	84	[b] 1.28	24.3	.599			Do.
Hattiesburg	Waterworks	8.95	5.24	6.42	2.39	8.73	6.32	20.5		34.9	1.35			A, p. 63.
Hickory	Hickory	54.4	4.39	13.9	4.11	.473	3.62	102	[b] .298	32.5	.839			A, p. 53.
Holly Springs	Holly Springs	10.8	2.34	6.42	2.04	.532	16	16.7		11.7	.199			A, p. 105.
Indianola	Well No. 1	272	2.72	.855	.308	.945	9.10	350	[b] 7.30	24.6	.998			A, p. 86.
Ittabena	Ittabena	92.5	4.85	4.06	1.68	3.16	4.98	124		28.4	2.59			A, p. 96.
Jackson	Jackson's	23.2	6.42	99.8	20.6	32.4	13.6	204		44.6	.787	138		A, p. 112.
Leflore	Pollard	40.4	7.51	11.8	5.76	.737	6.74	84.3		32.7	2.10			A, p. 109.
Leland	Leland	126	2.94	1.71	.259	1.44	25.5	147		25.3	1.50			A, p. 92.
Lexington	Oil mill	8.06	2.98	14.7	5.60	2.67	8.10	43		26.1	1.85			A, p. 102.
Do	Wilson	200	3.24	1.93	.409	1.35	5.49	257		39.2	1.15			Do.
Lyon (artesian)		143	3.3	1.1	.14	1.2	41	155	2.6	38	1.3			C.
Macon	Macon	363	32.2	9.20	3.47	[c] 1.83	400	180		11.9	.884			A, p. 45.
Macon, 2 miles E. of		326	7.46	4.99	2.10	.0287	328	231		10.	.998			A, p. 46.
Markville (artesian)		344	2	3.2	.66	6.9	4	447	4.1	47		.69		E.
Moorhead	Cotton factory	306	3.51	1.43	1.20	1.76	4.63	401	[b] 1.87	14.8	.657			A, p. 85.
Moss Point	Denny	190	1.36	1.64	.357	1.33	144	143	[b] 1.07	45.8	.798			A, p. 79.
Ocean Springs (artesian).		116	19	22	7.8	Trace.	111	146	([b])	43		8.5		B.
Ocean Springs	Ocean Springs	172	1.25	1.89	.325	2.75	100	143	1.11	21.9	.748			A, p. 77.
Pass Christian	Public	155	3.31	.499	.487	1.89	62	154	1.24	22.1	.698			A, p. 71.
Quitman	Quitman	37.3	5.74	30.1	7.10	3.59	4.63	110		36.7	.597			A, p. 59.
Riverside (artesian; 636 feet deep).		45	6.4	3.2	1.4	3.4	4.5	66		74	1.5			F.

[a] A=Miss. Agr. Exp. Station, Bull. No. 89. B=A. L. Metz, Tulane University. C=W. R. Perkins, Agricultural and Mechanical College of Mississippi. D=Illinois Central Railroad. E=B. W. Kilgore, Agricultural and Mechanical College of Mississippi. F=W. L. Hutchinson, Agricultural and Mechanical College of Mississippi. G=J. C. Mims, board of health, New Orleans, La.

[b] Phosphoric acid is taken as P_2O_5.

[c] Sulphuric acid is taken as SO_3.

ANALYSES—Continued.

Analyses of Mississippi waters, in parts per million—Continued.

DEEP WELLS—Continued.

Locality.	Name of well.	Sodium (Na).	Potassium (K).	Calcium (Ca).	Magnesium (Mg).	Sulphate radical (SO_4).	Chlorine (Cl).	Carbonate radical (CO_3).	Phosphate radical (PO_4).	Silica (SiO_2).	Iron and alumina ($Fe_2O_3+Al_2O_3$).	Iron (Fe).	Organic matter.	Authority.
Ruleville	Rule Brothers	182	3.63	1.50	.562	1.24	4.63	215	[a]5.06	18.6	0.947			A, p. 86.
Sardis	Railroad	19.9	1.40	14.14	1.44	3.47	19.2	18.3		14.2	.650			A, p. 99.
Scooba	Mineral	297	23.2	510	238	774	934	485		25	2.12			A, p. 51.
Scranton	Waterworks	223	1.50	2.07	.389	1.67	184	139	[a] 1.28	21.3	.748			A, p. 78.
Senatobia	Senatobia	8.35	.959	5.06	1.67	2.45	7.82	15.2		15.2	.399			A, p. 101.
Shubuta		460	21	2	1.4	20	4.7	605		21	1.1			F.
Starkville	Starkville	291	8.35	5.11	2.59	1.17	170	510		11.9	([b])	.898		A, p. 40.
Sunflower	Sunflower	245	1.74	1.43	.895	2.13	4.63	320	[a] 5.21	42.1	1.90			A, p. 88.
Taylorsville	Taylorsville	172	10.9	1.43	4.32	27.1	26.8	196	2.14	17	.726			A, p. 68.
Tchula (artesian)		227	2.2	2	.30	.17	5.6	296	.96	40				D.
Tunica	Tunica	38.1	3.31	1.21	.517	.657	3.79	51.7	[b].426	32.6	1.78			A, p. 81.
Tupelo	Railroad	38.6	4.69	14.8	2.97	5.83	69.5	21.1		9.98	.099			A, p. 26.
Tutwiler (artesian)		104		3.9	15.6	Trace.	12	169		32	.01			D.
Water Valley	Water Valley	6.27	.800	1.32	.650	1.07	4.31	8.07		11.9	.553			A, p. 106.
Do		14		8			7	23		26				D.
Waynesboro	Waynesboro	397	5.94	2.94	.722	1.64	71.7	465		26.5	1.37			A, p. 61.
Ways Bluff	Allison's	89.2	11.8			149	110			98				A, p. 111.
West		16		34	7	17	6	73		12	10			D.
West Point	West Point	35.5	8.01	9.06	2.17	3.16	6.82	63.5		9.78	2.19			A, p. 33.
Do	368-foot	121	2.88	11.4	2.17	1.23	75.5	487		7.68	.998			Do.
Wortham (artesian; 786 feet deep).		69	Trace.	29	2.3	18	8.2	132		27	3.1	7.6		G.
Yazoo	Main street	141	2.24	.787	.455	1.58	5.90	1.82	[a] 1.79	19.4	2.44			A, p. 97.
Do	Waterworks	62.3	5.30	10.7	3.61	12.9	7.58	95.7	[a] 1.15	231	16			Do.
Do	A. M. Kolm's	533	22.2	561	459	3160	570	240		23.8	([c])	9.96		A, p. 98.

[a] Phosphoric acid is taken as P_2O_5. [b] Iron bicarbonate is taken as $FeH_2(CO_3)_2$. [c] Iron carbonate is taken as $FeCO_3$.

SPRING WATERS.

Locality.	Name of spring.	Sodium (Na).	Potassium (K).	Calcium (Ca).	Magnesium. (Mg)	Sulphate radial (SO_4).	Chlorine (Cl).	Carbonate radical (CO_3).	Phosphate radical (PO_4).	Silica (SiO_2).	Iron and alumina (Fe_2O_3+Al_2O_3).	Iron (Fe).	Aluminum (Al)	Lithium (Li).	Organic matter.	Authority.[a]
Meridian	Arundel[b]	13.4		1.9	0.40	3.3	4.9	15								H.
Baldwyn	Baldwyn	4.12	4.61	3.35	1.37	7.76	2.48	10.4		17.6		5.93				A,p.25.
Hazelhurst	Brown Well No. 3	80	69	188	71	935	65	147		23		93	11		11	B.
Do	Brown Well No. 4	49	16	250	92	1106	45	117		21		37	29		8.2	Do.
Do	Brown Well No. 5	53	15	142	67	425	79	214		40		22	12	0.15	8.6	Do.
Do	Lowe's Well	[c]265	21	146	84	745	433	62		48		2.2	13			Do.
Blue Mountain	Blue Mountain	.76	1.4	3.8	6.4	4.4	1.2	21		11		.41			3.9	I.
Durant	Castalian Springs	65	79	188	52	855	26			126	83					J.
Raymond	Cooper's Well	121	4.7	162	96	936	131				58		17			K.
Weems	Donald No. 2	12	2.4	63	2.4	13	7.5	101		12		1.5				H.
Do	Mineral Springs No. 1.	4.1	.65	102	3.8	13	9.1	154		13		.98				Do.
Caledonia	Kolola South Spring.	1.7	4	6.7	2.8	3.6	5.6	35	1.9	9		10				F.
Do	Kolola North Spring.	2.2	3.3	6.6	2.0	5.2	5	34	1.9	6.7		9.9				Do.
Mammoth Springs	Mammoth Mineral Springs.	6	.68	12	2.4	2.2	7.8	24		19					5.8	Do.
Bay St. Louis	Park Mineral Springs.	16	1.1	5.6	2.7	5	13	31		19		3.8				L.
Springs	Pierce Springs	86		93	42	14	15	365		36		13				M.
Robinson Springs	Robinson Springs.	95	17	38	30	178	188	7		39		3.2				F.
Vossburg	Stafford Springs	9.5	7.6	101	4.7	12	10	159		34		1.3				B.
Quitman	S.H.Terrell Spring	46.6	3.73	49.3	2.64	6.49	5.88	328		32.8	1.4					A,p.59.

[a] H=R. W. Jones, University of Mississippi. I=William Krauss, Memphis, Tenn. J=L. G. Patterson, Agricultural and Mechanical College of Mississippi. K=J Lawrence Smith. L=W. F Hand, Agricultural and Mechanical College of Mississippi. M=R. W. Jones, University of Mississippi. For other references see footnote to table of deep wells, above.

[b] Hardness=18.75.

[c] Sodium crenate=5.96.

INDEX.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 159.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

Most of the above publications may be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
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B 217. Notes on the geology of southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 83 pp., 18 pls. (Out of stock.)

B 219. The ore deposits of Tonopah, Nevada (preliminary report), by J. E. Spurr. 1903. 31 pp., 1 pl. (Out of stock.)

PP 20. A reconnaissance in northern Alaska in 1901, by F. C. Schrader. 1904. 139 pp., 16 pls.

PP 21. The geology and ore deposits of the Bisbee quadrangle, Arizona, by F. L. Ransome. 1904. 168 pp., 29 pls.

WS 90. Geology and water resources of part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.

PP 25. The copper deposits of the Encampment district, Wyoming, by A. C. Spencer. 1904. 107 pp., 2 pls.

PP 26. Economic resources of northern Black Hills, by J. D. Irving, with chapters by S. F. Emmons and T. A. Jaggar, jr. 1904. 222 pp., 20 pls.

PP 27. Geological reconnaissance across the Bitterroot Range and the Clearwater Mountains in Montana and Idaho, by Waldemar Lindgren. 1904. 122 pp., 15 pls.

PP 31. Preliminary report on the geology of the Arbuckle and Wichita mountains in Indian Territory and Oklahoma, by J. A. Taff, with an appendix on reported ore deposits in the Wichita Mountains, by H. F. Bain. 1904. 97 pp., 8 pls.

B 235. A geological reconnaissance across the Cascade Range near the forty-ninth parallel, by G. O. Smith and F. C. Calkins. 1904. 103 pp., 4 pls.

B 236. The Porcupine placer district, Alaska, by C. W. Wright. 1904. 35 pp., 10 pls.

B 237. Igneous rocks of the Highwood Mountains, Montana, by L. V. Pirsson. 1904. 208 pp., 7 pls.

B 238. Economic geology of the Iola quadrangle, Kansas, by G. I. Adams, Erasmus Haworth, and W. R. Crane. 1904. 83 pp., 1 pl.

PP 32. Geology and underground water resources of the central Great Plains, by N. H. Darton. 1905. 433 pp., 72 pls.

WS 110. Contributions to hydrology of eastern United States, 1904; M. G. Fuller, geologist in charge. 1905. 211 pp., 5 pls.
B 242. Geology of the Hudson Valley between the Hoosic and the Kinderhook, by T. Nelson Dale. 1904. 63 pp., 3 pls.
PP 34. The Delavan lobe of the Lake Michigan glacier of the Wisconsin stage of glaciation and associated phenomena, by W. C. Alden. 1904. 106 pp., 15 pls.
PP 35. Geology of the Perry Basin in southeastern Maine, by G. O. Smith and David White. 1905. 107 pp., 6 pls.
B 243. Cement materials and industry of the United States, by E. C. Eckel. 1905. 395 pp., 15 pls.
B 246. Zinc and lead deposits of northwestern Illinois, by H. F. Bain. 1904. 56 pp., 5 pls.
B 247. The Fairhaven gold placers of Seward Peninsula, Alaska, by F. H. Moffit. 1905. 85 pp., 14 pls.
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B 250. The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposit, by G. C. Martin. 1905. 64 pp., 7 pls.
B 251. The gold placers of the Fortymile, Birch Creek, and Fairbanks regions, Alaska, by L. M. Prindle. 1905. 89 pp., 16 pls.
WS 118. Geology and water resources of a portion of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls.
B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.
PP 36. The lead, zinc, and fluorspar deposits of western Kentucky, by E. O. Ulrich and W. S. Tangier Smith. 1905. 218 pp., 15 pls.
PP 38. Economic geology of the Bingham mining district, of Utah, by J. M. Boutwell, with a chapter on areal geology, by Arthur Keith, and an introduction on general geology, by S. F. Emmons. 1905. 413 pp., 49 pls.
PP 41. The geology of the central Copper River region, Alaska, by W. C. Mendenhall. 1905. 133 pp., 20 pls.
B 254. Report of progress in the geological resurvey of the Cripple Creek district, Colorado, by Waldemar Lindgren and F. L. Ransome. 1904. 36 pp.
B 255. The fluorspar deposits of southern Illinois, by H. Foster Bain. 1905. 75 pp., 6 pls.
B 256. Mineral resources of the Elders Ridge quadrangle, Pennsylvania, by R. W. Stone. 1905. 86 pp., 12 pls.
B 257. Geology and paleontology of the Judith River beds, by T. W. Stanton and J. B. Hatcher, with a chapter on fossil plants, by F. H. Knowlton. 1905. 174 pp., 19 pls.
PP 42. Geology of the Tonopah mining district, Nevada, by J. E. Spurr. 1905. 295 pp., 23 pls.
WS 123. Geology and underground water conditions of the Jornada del Muerto, New Mexico, by C. R. Keyes. 1905. 42 pp., 9 pls.
WS 136. Underground waters of Salt River Valley, Arizona, by W. T. Lee. 1905. 194 pp., 24 pls.
PP 43. The copper deposits of the Clifton-Morenci district, Arizona, by Waldemar Lindgren. 1905. 375 pp., 25 pls.
B 265. Geology of the Boulder district, Colorado, by N. M. Fenneman. 1905. 101 pp., 5 pls.
B 267. The copper deposits of Missouri, by H. F. Bain and E. O. Ulrich. 1905. 52 pp., 1 pl.
PP 44. Underground water resources of Long Island, New York, by A. C. Veatch, and others. 1905. 394 pp., 34 pls.
WS 148. Geology and water resources of Oklahoma, by C. N. Gould. 1905. 178 pp., 22 pls.
B 270. The configuration of the rock floor of Greater New York, by W. H. Hobbs. 1905. 96 pp., 5 pls.
B 272. Taconic physiography, by T. N. Dale. 1905. 52 pp., 14 pls. (Out of stock.)
PP 45. The geography and geology of Alaska, a summary of existing knowledge, by A. H. Brooks, with a section on climate, by Cleveland Abbe, jr., and a topographic map and description thereof, by R. U. Goode. 1906. 327 pp., 34 pls.
B 273. The drumlins of southeastern Wisconsin (preliminary paper), by W. C. Alden. 1905. 46 pp. 9 pls.
PP 46. Geology and underground water resources of northern Louisiana and southern Arkansas, by A. C. Veatch. 1906. — pp., 51 pls.
PP 49. Geology and mineral resources of part of the Cumberland Gap coal field, Kentucky, by G. H. Ashley and L. C. Glenn, in cooperation with the State Geological Department of Kentucky, C. J. Norwood, curator. 1906. 239 pp., 40 pls.
PP 50. The Montana lobe of the Keewatin ice sheet, by F. H. H. Calhoun. 1906. 62 pp., 7 pls.
B 277. Mineral resources of Kenai Peninsula, Alaska: Gold fields of the Turnagain Arm region, by F. H. Moffit, and the coal fields of Kachemak Bay region, by R. W. Stone. 1906. 80 pp., 18 pls.
WS 154. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 64 pp., 15 pls.
B 278. Geology and coal resources of the Cape Lisburne region, Alaska, by A. J. Collier. 1906. 54 pp., 9 pls.
B 279. Mineral resources of the Kittanning and Rural Valley quadrangles, Pennsylvania, by Charles Butts. 1906. — pp., 11 pls.
B 280. The Rampart gold placer region, Alaska, by L. M. Prindle and F. L. Hess. 1906. 54 pp., 7 pls.

B 282. Oil fields of the Texas-Louisiana Gulf coastal plain, by N. M. Fenneman. 1906. 146 pp., 11 pls.
WS 157. Undergound water in the valleys of Utah Lake and Jordan River, Utah, by G. B. Richardson. 1906. 81 pp., 9 pls.
PP 51. Geology of the Bighorn Mountains, by N. H. Darton. 1906. 129 pp., 47 pls.
WS 158. Preliminary report on the geology and underground waters of the Roswell artesian area, New Mexico, by C. A. Fisher. 1906. 29 pp., 9 pls.
PP 52. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906. 90 pp., 28 pls.
WS 159. Summary of underground-water resources of Mississippi, by A. F. Crider and L. C. Johnson. 1906. 86 pp., 6 pls.

SERIES O—UNDERGROUND WATERS.

WS 4. A reconnaissance in southeastern Washington, by I. C. Russell. 1897. 96 pp., 7 pls. (Out of stock.)
WS 6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls. (Out of stock.)
WS 7. Seepage waters of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls. (Out of stock.)
WS 12. Underground waters of southeastern Nebraska, by N. H. Darton. 1898. 56 pp., 21 pls. (Out of stock.)
WS 21. Wells of northern Indiana, by Frank Leverett. 1899. 82 pp., 2 pls. (Out of stock.)
WS 26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett. 1899. 64 pp. (Out of stock.)
WS 30. Water resources of the Lower Peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls. (Out of stock.)
WS 31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., 4 pls. (Out of stock.)
WS 34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 19 pls.
WS 53. Geology and water resources of Nez Perces County, Idaho, Pt. I, by I. C. Russell. 1901. 86 pp., 10 pls. (Out of stock.)
WS 54. Geology and water resources of Nez Perces County, Idaho, Pt. II, by I. C. Russell. 1901. 87–141 pp. (Out of stock.)
WS 55. Geology and water resources of a portion of Yakima County, Wash., by G. O. Smith. 1901. 68 pp., 7 pls. (Out of stock.)
WS 57. Preliminary list of deep borings in the United States, Pt. I, by N. H. Darton. 1902. 60 pp. (Out of stock.)
WS 59. Development and application of water in southern California, Pt. I, by J. B. Lippincott. 1902. 95 pp., 11 pls. (Out of stock.)
WS 60. Development and application of water in southern California, Pt. II, by J. B. Lippincott. 1902. 96–140 pp. (Out of stock.)
WS 61. Preliminary list of deep borings in the United States, Pt. II, by N. H. Darton. 1902. 67 pp. (Out of stock.)
WS 67. The motions of underground waters, by C. S. Slichter. 1902. 106 pp., 8 pls. (Out of stock.)
B 199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.
WS 77. Water resources of Molokai, Hawaiian Islands, by Waldemar Lindgren. 1903. 62 pp., 4 pls.
WS 78. Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 53 pp., 2 pls.
PP 17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.
WS 90. Geology and water resources of a part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.
WS 101. Underground waters of southern Louisiana, by G. D. Harris, with discussions of their uses for water supplies and for rice irrigation, by M. L. Fuller. 1904. 98 pp., 11 pls.
WS 102. Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller. 1904. 522 pp.
WS 104. Underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls.
WS 106. Water resources of the Philadelphia district, by Florence Bascom. 1904. 75 pp., 4 pls.
WS 110. Contributions to the hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge. 1904. 211 pp., 5 pls.
PP 32. Geology and underground-water resources of the central Great Plains, by N. H. Darton. 1904. 433 pp., 72 pls. (Out of stock.)
WS 111. Preliminary report on underground waters of Washington, by Henry Landes. 1904. 85 pp., 1 pl.
WS 112. Underflow tests in the drainage basin of Los Angeles River, by Homer Hamlin. 1904. 55 pp., 7 pls.
WS 114. Underground waters of eastern United States; M. L. Fuller, geologist in charge. 1904. 285 pp., 18 pls.
WS 118. Geology and water resources of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls.

B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.

WS 120. Bibliographic review and index of papers relating to underground waters published by the United States Geological Survey, 1879-1904, by M. L. Fuller. 1905. 128 pp.

WS 122. Relation of the law to underground waters, by D. W. Johnson. 1905. 55 pp.

WS 123. Geology and underground water conditions of the Jornada del Muerto, New Mexico, by C. R. Keyes. 1905. 42 pp., 9 pls.

WS 136. Underground waters of the Salt River Valley, by W. T. Lee. 1905. 194 pp., 24 pls.

B 264. Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch. 1905. 106 pp.

PP 44. Underground water resources of Long Island, New York, by A. C. Veatch and others. 1905. 394 pp., 34 pls.

WS 137. Development of underground waters in the eastern coastal plain region of southern California, by W. C. Mendenhall. 1905. 140 pp., 7 pls.

WS 138. Development of underground waters in the central coastal plain region of southern California, by W. C. Mendenhall. 1905. 162 pp., 5 pls.

WS 139. Development of underground waters in the western coastal plain region of southern California, by W. C. Mendenhall. 1905. 105 pp., 7 pls.

WS 140. Field measurements of the rate of movement of underground waters, by C. S. Slichter. 1905. 122 pp., 15 pls.

WS 141. Observations on the ground waters of Rio Grande Valley, by C. S. Slichter. 1905. 83 pp., 5 pls.

WS 142. Hydrology of San Bernardino Valley, California, by W. C. Mendenhall. 1905. 124 pp., 13 pls.

WS 145. Contributions to the hydrology of eastern United States; M. L. Fuller, geologist in charge. 1905. 220 pp., 6 pls.

WS 148. Geology and water resources of Oklahoma, by C. N. Gould. 1905. 178 pp., 22 pls.

WS 149. Preliminary list of deep borings in the United States, second edition, with additions, by N. H. Darton. 1905. 175 pp.

PP 46. Geology and underground water resources of northern Louisiana and southern Arkansas, by A. C. Veatch. 1906. — pp., 51 pls.

WS 153. The underflow in Arkansas Valley in western Kansas, by C. S. Slichter. 1906. 90 pp., 3 pls.

WS 154. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 61 pp., 15 pls.

WS 155. Fluctuations of the water level in wells, with special reference to Long Island, New York, by A. C. Veatch. 1906. 83 pp.

WS 157. Underground water in the valleys of Utah Lake and Jordan River, Utah, by G. B. Richardson. 1906. 81 pp.

WS 158. Preliminary report on the geology and underground waters of the Roswell artesian area, New Mexico, by C. A. Fisher. 1906. 29 pp., 9 pls.

PP 52. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906. 90 pp., 28 pls.

WS 159. Summary of underground water resources of Mississippi, by A. F. Crider and L. C. Johnson. 1906. 86 pp., 6 pls.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian well prospects in the Atlantic coastal plain region, by N. H. Darton Bulletin No. 138.

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UNITED STATES GEOLOGICAL SURVEY,

WASHINGTON, D. C.

JULY, 1906.

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Water-Supply and Irrigation Paper No. 160 Series O, Underground Waters, 58

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

UNDERGROUND-WATER PAPERS

1906

MYRON L. FULLER

GEOLOGIST IN CHARGE

WASHINGTON

GOVERNMENT PRINTING OFFICE

1906

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ILLUSTRATIONS.

UNDERGROUND-WATER PAPERS, 1906.

MYRON L. FULLER,
Geologist in Charge.

WORK OF THE EASTERN SECTION OF HYDROLOGY IN 1905, AND PUBLICATIONS RELATING TO UNDERGROUND WATERS.

By MYRON L. FULLER.

INTRODUCTION.

The present report is the fourth volume of miscellaneous short contributions, the preceding volumes of which appeared under the title of "Contributions to the Hydrology of Eastern United States." The change in name is made with the view of more clearly indicating the scope of the report.

The present volume contains eleven papers by six authors, mainly connected with the eastern section of the division of hydrology. These papers are predominantly of a theoretical or general character; papers relating to local areas, such as the quadrangle descriptions appearing in the previous reports, are omitted, as it has been shown that there is less demand for such descriptive contributions than for general or theoretical papers, which often have practical engineering and geologic applications. The fact that the report makes available a considerable number of short contributions which could not otherwise be satisfactorily placed before the public is one of the leading reasons for its publication.

As in previous reports, the present volume covers a wide range of subjects, including papers on (1) artesian nomenclature and the representation of ground-water data on maps, (2) occurrence of ground waters in igneous rocks, (3) description of the ground-water resources of special localities, (4) the use of wells in the drainage of wet lands, (5) the amount of ground water in the earth, (6) a method of tracing underground currents, (7) spring waters of peculiar composition, (8) depths reached by boring, (9) flowing wells and springs, (10) problems of water contamination, and (11) improvement of water in wells.

WORK OF THE EASTERN SECTION OF HYDROLOGY.

Personnel.—Of the permanent members of the section, M. L. Fuller has continued in charge of the work in eastern United States, and in addition to executive duties has given special attention to the water supplies of Pleistocene and Coastal Plain deposits. F. G. Clapp has been engaged mainly in the investigation of Pleistocene geology and its relation to underground waters. E. E. Ellis has devoted the greater part of the season to a study of the occurrence of ground waters in igneous rocks, especially those of Connecticut. Isaiah Bowman has been engaged in field work and in the preparation of a report on the methods of well drilling in use in different parts of the country. Samuel Sanford has had charge

of the collection of deep-well records and samples. B. L. Johnson has devoted his time to a large extent to the preparation of a bibliography of the underground waters of the United States.

In addition to the permanent force the following have been engaged in work for the section during the year: W. S. Bayley, on underground waters of Maine; G. N. Knapp, in New Jersey; L. W. Stephenson, in North Carolina; S. W. McCallie, in Georgia; E. A. Smith, in Alabama; L. C. Glenn, in Tennessee and Kentucky; A. C. Veatch, A. F. Crider, and L. W. Stephenson, in Arkansas; E. M. Shepard, in Missouri; W. H. Norton and Howard E. Simpson, in Iowa; C. W. Hall, in Minnesota, and Frank Leverett, in Michigan. E. F. Lines and D. F. MacDonald have assisted in office work.

Office work.—The office work for the year has consisted, in addition to executive duties, of the preparation of a bibliography of the underground waters of the United States, and of tables relating to the discharge and other features connected with artesian wells, and of the systematic collection of well records and samples. Both the executive work and the collection of samples involve a very extended correspondence and the furnishing of information in regard to wells and underground-water conditions to a large number of applicants. Separate reports on the bibliography of underground waters, artesian tables, and collection of well samples are in preparation.

Theoretical investigations.—The principal theoretical and technical investigations undertaken in 1905 related to the fluctuations of the water level in wells, by A. C. Veatch, and the methods of well drilling by Isaiah Bowman. The report on the fluctuation of wells is in press, and that on well drilling is nearly completed.

Surveys.—Detailed surveys of underground-water problems have been conducted in Connecticut by H. E. Gregory and E. E. Ellis; in Iowa, by W. H. Norton and Howard E. Simpson; in Arkansas, by M. L. Fuller, A. F. Crider, and L. W. Stephenson; and in North Carolina by L. W. Stephenson and B. L. Johnson. In Connecticut and Arkansas the work is completed and reports are in preparation. In Iowa and North Carolina the surveys are incomplete and will require further work the coming season.

Reports.—The following reports have been published since January 1, 1905:

Bibliographic review and index of papers relating to underground waters published by the United States Geological Survey, 1879-1904, by M. L. Fuller: Water-Sup. and Irr. Paper No. 120, 128 pp.

Contributions to the hydrology of eastern United States, 1904, M. L. Fuller, geologist in charge: Water-Sup. and Irr. Paper No. 110, 211 pp.

Underground waters of eastern United States, M. L. Fuller, geologist in charge: Water-Sup. and Irr. Paper No. 114, 285 pp.

Relation of the law to underground waters, by D. W. Johnson: Water-Sup. and Irr. Paper No. 122, 55 pp.

Field measurements of the rate of movement of underground waters, by C. S. Slichter: Water-Sup. and Irr. Paper No. 140, 122 pp.

Contributions to the hydrology of eastern United States, 1905, M. L. Fuller, geologist in charge: Water-Sup. and Irr. Paper No. 145, 220 pp.

Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch: Bull. No. 264, 106 pp.

Underground water resources of Long Island, New York, by A. C. Veatch: Prof. Paper No. 44, 394 pp.

In addition the following papers have been received from the authors and transmitted for publication:

Fluctuations of the water level in wells, with special reference to Long Island, New York, by A. C. Veatch: Water-Sup. and Irr. Paper No. 155.

Geology and underground waters of Mississippi, by A. F. Crider and L. C. Johnson: Water-Sup. and Irr. Paper No. 159.

Geology and water resources of northern Louisiana and southern Arkansas, by A. C. Veatch: Prof. Paper No. 46.

The following papers are nearly completed:

Flowing wells of the southern portion of the lower Peninsula of Michigan, by Frank Leverett.

Flowing wells of the northern and central portions of the lower Peninsula of Michigan, by Frank Leverett.

Artesian waters of Missouri, by E. M. Shepard.

Underground water resources of Tennessee and Kentucky west of Tennessee River, and of an adjacent area in Illinois, by L. C. Glenn.
Underground water resources of Minnesota, by C. W. Hall.

Preliminary reports on the wells and springs of Virginia and South Carolina were prepared by M. L. Fuller for the State surveys in accordance with plans of cooperation approved by the Director.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

The results of the work of the Survey on underground waters and springs are published as reports of various kinds. All but the folios and monographs, which are sold at cost, are for free distribution and can be obtained on application to the Director until the editions are exhausted. A number have been delivered to members of Congress for distribution.

A full subject index of the Survey publications on underground waters is contained in Water-Supply and Irrigation Paper No. 120, entitled "Bibliographic review and index of papers relating to underground waters published by the United States Geological Survey."

A list of papers published by the Survey since Water-Supply Paper No. 120 was prepared, and brief references to the most important publications of the Survey, are given below:

GENERAL DESCRIPTIVE REPORTS.

ALABAMA.

Alabama (water resources), by E. A. Smith: Water-Sup. and Irr. Paper No. 114, 1905, pp. 164-170.
For other reports see Water-Supply Paper No. 102.

ARKANSAS.

Summary of the water supply of the Ozark region in northern Arkansas, by George I. Adams: Water-Sup. and Irr. Paper No. 110, 1905, pp. 179-182.
Northern Arkansas (water resources), by A. H. Purdue: Water-Sup. and Irr. Paper No. 114, 1905, pp. 188-197.
Water resources of the Winslow quadrangle, Arkansas, by A. H. Purdue: Water-Sup. and Irr. Paper No. 145, 1905, pp. 84-87.
Water resources of the contact region between the Paleozoic and Mississippi embayment deposits in northern Arkansas, by A. H. Purdue: Water-Sup. and Irr. Paper No. 145, 1905, pp. 88-119.
For other reports see Water-Supply Paper No. 102.

CALIFORNIA.

Water problems of Santa Barbara, Cal., by J. B. Lippincott: Water-Sup. and Irr. Paper No. 116, 1905.
For other reports see Water-Supply Papers Nos. 59 and 60.

COLORADO.

Geology and underground-water resources of the central Great Plains, by N. H. Darton: Prof. Paper No. 32, 1904.
For other reports see Sixteenth, Seventeenth, and Twenty-first Annual Reports, Bulletin No. 131, and Folios 36, 68, and 71.

CONNECTICUT.

Drilled wells of the Triassic area of the Connecticut Valley, by W. H. C. Pynchon: Water-Sup. and Irr. Paper No. 110, 1905, pp. 65-94.
Triassic rocks of the Connecticut Valley as a source of water supply, by M. L. Fuller: Water-Sup. and Irr. Paper No. 110, 1905, pp. 95-112.
Connecticut (water resources), by H. E. Gregory: Water-Sup. and Irr. Paper No. 114, 1905, pp. 76-81.
For other reports see Water-Supply Paper No. 102.

CUBA.

Notes on the hydrology of Cuba, by M. L. Fuller: Water-Sup. and Irr. Paper No. 110, 1905, pp. 183-200.

DELAWARE.

Delaware (water resources), by N. H. Darton: Water-Sup. and Irr. Paper No. 114, 1905, pp. 111-113.
For other reports see Bulletin No. 138.

DISTRICT OF COLUMBIA.

District of Columbia (water resources), by N. H. Darton and M. L. Fuller: Water-Sup. and Irr. Paper No. 114, 1905, pp. 124-126.
For other reports see Bulletin No. 138 and Folio 70.

FLORIDA.

Florida (water resources), by M. L. Fuller: Water-Sup. and Irr. Paper No. 114, 1905, pp. 159-163.
For other reports see Water-Supply Paper No. 102.

GEORGIA.

Georgia (water resources), by S. W. McCallie: Water-Sup. and Irr. Paper No. 114, 1905, pp. 153-158.
For other reports see Water-Supply Paper No. 102 and Bulletin No. 138.

IDAHO.

See Water-Supply Papers Nos. 54, 55, 78, Bulletin No. 199, and Folio 104.

HAWAII.

See Water-Supply Paper No. 77.

ILLINOIS.

Illinois (water resources), by Frank Leverett: Water-Sup. and Irr. Paper No. 114, 1905, pp. 248-257.
For other reports see Seventeenth Annual Report and Folios 67, 81, and 105.

INDIANA.

Indiana (water resources), by Frank Leverett: Water-Sup. and Irr. Paper No. 114, 1905, pp. 258-264.
For other reports see Water-Supply Papers Nos. 21 and 26, Eighteenth Annual Report, and Folios 67, 81, and 105.

IOWA.

Iowa (water resources), by W. H. Norton: Water-Sup. and Irr. Paper No. 114, 1905, pp. 220-225.
Water supplies at Waterloo, Iowa, by W. H. Norton: Water-Sup. and Irr. Paper No. 145, 1905, pp. 148-155.
For other reports see Sixteenth Annual Report.

KANSAS.

Geology and underground-water resources of the central Great Plains, by N. H. Darton: Prof. Paper No. 32, 1904, pp. 433.
Water resources of the Joplin district, Missouri-Kansas, by W. S. Tangier Smith: Water-Sup. and Irr. Paper No. 145, 1905, pp. 74-83.
For other reports see Water-Supply Paper No. 6, Twenty-second Annual Report, and Bulletin No. 131.

KENTUCKY.

Water resources of the Middlesboro-Harlan region of southeastern Kentucky, by George H. Ashley: Water-Sup. and Irr. Paper No. 110, 1905, pp. 177-178.
Kentucky (water resources), by L. C. Glenn: Water-Sup. and Irr. Paper No. 114, 1905, pp. 205-208.
For other reports see Water-Supply Paper No. 102.

LOUISIANA.

Louisiana (water resources), by A. C. Veatch: Water-Sup. and Irr. Paper No. 114, 1905, pp. 179-187.
For other reports see Water-Supply Paper No. 101.

MAINE.

Maine (water resources), by W. S. Bayley: Water-Sup. and Irr. Paper No. 114, 1905, pp. 41-56.
Water resources of the Portsmouth-York region, New Hampshire and Maine, by George Otis Smith: Water-Sup. and Irr. Paper No. 145, 1905, pp. 120-128.
Water supply from glacial gravels near Augusta, Me., by George Otis Smith: Water-Sup. and Irr. Paper No. 145, 1905, pp. 156-160.
For other reports see Water-Supply Paper No. 101.

MARYLAND.

Water resources of the Accident and Grantsville quadrangles, Maryland, by G. C. Martin: Water-Sup. and Irr. Paper No. 110, 1905, pp. 168-170.
Water resources of the Frostburg and Flintstone quadrangles, Maryland and West Virginia, by G. C. Martin: Water-Sup. and Irr. Paper No. 110, 1905, pp. 171-173.
Maryland (water resources), by N. H. Darton and M. L. Fuller: Water-Sup. and Irr. Paper No. 114, 1905, pp. 114-123.
Water resources of the Pawpaw and Hancock quadrangles, West Virginia, Maryland, and Pennsylvania, by George W. Stose and George C. Martin: Water-Sup. and Irr. Paper No. 145, 1905, pp. 58-63.
For other reports see Bulletin No. 138 and Folios 13, 23, and 70.

MASSACHUSETTS.

Drilled wells of the Triassic area of the Connecticut Valley, by W. H. C. Pynchon: Water-Sup. and Irr. Paper No. 110, 1905, pp. 65-94.

Triassic rocks of the Connecticut Valley as a source of water supply, by M. L. Fuller: Water-Sup. and Irr. Paper No. 110, 1905, pp. 95-112.

Water resources of the Taconic quadrangle, New York, Massachusetts, and Vermont, by F. B. Taylor: Water-Sup. and Irr. Paper No. 110, 1905, pp. 130-133.

Massachusetts and Rhode Island (water resources), by W. O. Crosby: Water-Sup. and Irr. Paper No. 114, 1905, pp. 68-75.

Water supply from the delta type of sand plain, by W. O. Crosby: Water-Sup. and Irr. Paper No. 145, 1905, pp. 161-178.

For other reports see Water-Supply Paper No. 102.

MICHIGAN.

A ground-water problem in southeastern Michigan, by Myron L. Fuller: Water-Sup. and Irr. Paper No. 145, 1905, pp. 129-147.

For other reports see Water-Supply Papers Nos. 30, 31, and 102.

MINNESOTA.

Minnesota (water resources), by C. W. Hall: Water-Sup. and Irr. Paper No. 114, 1905, pp. 226-232.

For other reports see Water-Supply Paper No. 102.

MISSISSIPPI.

Mississippi (water resources), by L. C. Johnson: Water-Sup. and Irr. Paper No. 114, 1905, pp. 171-178.

For other reports see Water-Supply Paper No. 102.

MISSOURI.

Spring system of the Decaturville dome, Camden County, Missouri, by E. M. Shepard: Water-Sup. and Irr. Paper No. 110, 1905, pp. 113-125.

Missouri (water resources), by E. M. Shepard: Water-Sup. and Irr. Paper No. 114, 1905, pp. 209-219.

Water resources of the Joplin district, Missouri-Kansas, by W. S. Tangier Smith: Water-Sup. and Irr. Paper No. 145, 1905, pp. 74-83.

For other reports see Water-Supply Paper No. 102.

NEBRASKA.

Geology and underground-water resources of the central Great Plains, by N. H. Darton: Prof. Paper No. 32, 1904.

For other reports see Water-Supply Paper No. 12, Sixteenth, Nineteenth, and Twenty-second Annual Reports, Bulletin 131, Professional Paper No. 17, and Folios 85 and 108.

NEW HAMPSHIRE.

New Hampshire (water resources), by M. L. Fuller: Water-Sup. and Irr. Paper No. 114, 1905, pp. 57-59.

Water resources of the Portsmouth-York region, New Hampshire and Maine, by George Otis Smith: Water-Sup. and Irr. Paper No. 145, 1905, pp. 120-128.

For other reports see Water-Supply Paper No. 102.

NEW JERSEY.

Water resources of the central and southwestern highlands of New Jersey, by Laurence La Forge: Water-Sup. and Irr. Paper No. 110, 1905, pp. 141-155.

New Jersey (water resources), by G. N. Knapp: Water-Sup. and Irr. Paper No. 114, 1905, pp. 93-103.

For other reports see Water-Supply Paper No. 106 and Bulletin 138.

NEW MEXICO.

Geology and underground-water conditions of the Jornada Del Muerto, New Mexico, by C. R. Keyes: Water-Sup. and Irr. Paper No. 123, 1905.

For other reports see Twenty-second Annual Report.

NEW YORK.

The new artesian water supply at Ithaca, N. Y., by Francis L. Whitney: Water-Sup. and Irr. Paper No. 110, 1905, pp. 55-64.

Water resources of the Fort Ticonderoga quadrangle, Vermont and New York, by T. Nelson Dale: Water-Sup. and Irr. Paper No. 110, 1905, pp. 126-129.

Water resources of the Taconic quadrangle, New York, Massachusetts, and Vermont, by F. B. Taylor: Water-Sup. and Irr. Paper No. 110, 1905, pp. 130-133.

Water resources of the Watkins Glen quadrangle, New York, by Ralph S. Tarr: Water-Sup. and Irr. Paper No. 110, 1905, pp. 134-140.

New York (water resources), by F. B. Weeks: Water-Sup. and Irr. Paper No. 114, 1905, pp. 82-92.

Water resources of the Catatonk area, New York, by E. M. Kindle: Water-Sup. and Irr. Paper No. 145, 1905, pp. 53-57.

Waters of a gravel-filled valley near Tully, N. Y., by George B. Hollister: Water-Sup. and Irr. Paper No. 145, 1905, pp. 179-184.

For other reports see Water-Supply Paper No. 102 and Bulletin No. 138.

NORTH CAROLINA.

Water resources of the Cowee and Pisgah quadrangles, North Carolina, by Hoyt S. Gale: Water-Sup. and Irr. Paper No. 110, 1905, pp. 174-176.

North Carolina (water resources), by M. L. Fuller: Water-Sup. and Irr. Paper No. 114, 1905, pp. 136-139.

For other reports see Bulletin No. 138 and Folio 80.

NORTH DAKOTA.

See Seventeenth Annual Report.

OHIO.

Ohio (water resources), by Frank Leverett: Water-Sup. and Irr. Paper No. 114, 1905, pp. 265-270.

For other reports see Eighteenth and Nineteenth Annual Reports.

OKLAHOMA.

See Twenty-second Annual Report.

OREGON.

See Water-Supply Papers Nos. 7, 8, and 252.

PENNSYLVANIA.

Water resources of the Chambersburg and Mercersburg quadrangles, Pennsylvania, by George W. Stose: Water-Sup. and Irr. Paper No. 110, 1905, pp. 156-158.

Water resources of the Curwensville, Patton, Ebensburg, and Barnesboro quadrangles, Pennsylvania, by F. G. Clapp: Water-Sup. and Irr. Paper No. 110, 1905, pp. 159-163.

Water resources of the Elders Ridge quadrangle, Pennsylvania, by Ralph W. Stone: Water-Sup. and Irr. Paper No. 110, 1905, pp. 164-165.

Water resources of the Waynesburg quadrangle, Pennsylvania, by Ralph W. Stone: Water-Sup. and Irr. Paper No. 110, 1905, pp. 166-167.

Pennsylvania (water resources), by M. L. Fuller: Water-Sup. and Irr. Paper No. 114, 1905, pp. 104-110.

Water resources of the Pawpaw and Hancock quadrangles, West Virginia, Maryland, and Pennsylvania, by George W. Stose and George C. Martin: Water-Sup. and Irr. Paper No. 145, 1905, pp. 58-63.

Waynesburg folio, Pennsylvania, by Ralph W. Stone: Geologic Atlas U. S., folio 121, 1905.

For other reports see Water-Supply Paper No. 106.

RHODE ISLAND.

Massachusetts and Rhode Island (water resources), by W. O. Crosby: Water-Sup. and Irr. Paper No. 114, 1905, pp. 68-75.

For other reports see Water-Supply Paper No. 102.

SOUTH CAROLINA.

South Carolina (water resources), by L. C. Glenn: Water-Sup. and Irr. Paper No. 114, 1905, pp. 140-152.

For other reports see Bulletin No. 138.

SOUTH DAKOTA.

Geology and underground-water resources of the central Great Plains, by N. H. Darton: Prof. Paper No. 32, 1904.

Huron folio, South Dakota, by J. E. Todd: Geologic Atlas U. S., folio 113, 1904.

De Smet folio, South Dakota, by J. E. Todd and C. M. Hall: Geologic Atlas U. S., folio 114, 1904.

For other reports see Water-Supply Papers Nos. 34 and 90, Seventeenth, Eighteenth, and Twenty-first Annual Reports, and Folios 85, 96, 97, 99, 100, 107, and 108.

TENNESSEE.

Tennessee and Kentucky (water resources), by L. C. Glenn: Water-Sup. and Irr. Paper No. 114, 1905, pp. 198-208.

For other reports see Water-Supply Paper No. 102.

TEXAS.

See Eighteenth, Twenty-first, and Twenty-second Annual Reports and Folio 42.

VERMONT.

Water resources of the Fort Ticonderoga quadrangle, Vermont and New York, by T. Nelson Dale: Water-Sup. and Irr. Paper No 110, 1905, pp. 126-129.

Water resources of the Taconic quadrangle, New York, Massachusetts, and Vermont, by F. B. Taylor: Water-Sup. and Irr. Paper No. 110, 1905, pp. 130-133.

Vermont (water resources), by G. H. Perkins. Water-Sup. and Irr. Paper No. 114, 1905, pp. 60-67.

For other reports see Water-Supply Paper No. 102.

VIRGINIA.

Virginia (water resources), by N. H. Darton and M. L. Fuller: Water-Sup. and Irr. Paper No. 114, 1905, pp. 127-135.

For other reports see Bulletin No. 138 and Folios 13, 23, 70, and 80.

WASHINGTON.

See Water-Supply Papers Nos. 4 and 55, and Folio 86.

WEST VIRGINIA.

Water resources of the Frostburg and Flintstone quadrangles, Maryland and West Virginia, by G. C. Martin: Water-Sup. and Irr. Paper No. 110, 1905, pp. 171-173.
West Virginia (water resources), by M. L. Fuller: Water-Sup. and Irr. Paper No. 114, 1905, pp. 271-272.
Water resources of the Pawpaw and Hancock quadrangles, West Virginia, Maryland, and Pennsylvania, by George W. Stose and George C. Martin: Water-Sup. and Irr. Paper No. 145, 1905, pp. 58-63.
Water resources of the Nicholas quadrangle, West Virginia, by George H. Ashley: Water-Sup. and Irr. Paper No. 145, 1905, pp. 64-66.

WISCONSIN.

Wisconsin district (water resources), by A. R. Shultz: Water-Sup. and Irr. Paper No. 114, 1905, pp. 233-241.
Water resources of the Mineral Point quadrangle, Wisconsin, by U. S. Grant: Water-Sup. and Irr. Paper No. 145, 1905, pp. 67-73.

WYOMING.

Geology and underground-water resources of the central Great Plains, by N. H. Darton: Prof. Paper No. 32, 1904.
For other reports see Twenty-first Annual Report and Folio 10.

SPRINGS AND SPRING DEPOSITS.

Contributions to hydrology of eastern United States, 1904, M. L. Fuller, geologist in charge: Water-Sup. and Irr. Paper No. 110, 1905.
Spring system of the Decaturville dome, Camden County, Missouri, by E. M. Shepard: Water-Sup. and Irr. Paper No. 110, 1905, pp. 113-125.
Notes on the hydrology of Cuba, by M. L. Fuller: Water-Sup. and Irr. Paper, No. 110, 1905, pp. 183-200.
Waters of a gravel-filled valley near Tully, New York, by George B. Hollister: Water-Sup. and Irr. Paper No. 145, 1905, pp. 179-184.
Notes on certain hot springs of the southern United States, by Walter Harvey Weed: Water-Sup. and Irr. Paper No. 145, 1905, pp. 185-206.
Notes on certain large springs of the Ozark region, Missouri and Arkansas, compiled by Myron L. Fuller: Water-Sup. and Irr. Paper No. 145, 1905, pp. 207-210.
For other reports see Ninth Annual Report, Bulletins Nos. 32 and 47, and Folio 30.

MINERAL AND POTABLE WATERS.

See Fourteenth Annual Report, Bulletins Nos. 32 and 47, and the various reports on Mineral Resources from 1883 to 1904.

ARTESIAN REQUISITES, MOVEMENTS OF GROUND WATERS, ETC.

Description of underflow meter used in measuring the velocity and direction of underground water, by Charles S. Slichter: Water-Sup. and Irr. Paper No. 110, 1905, pp. 17-31.
Underflow tests in the drainage basin of Los Angeles River, by Homer Hamlin: Water-Sup. and Irr. Paper No. 112, 1905.
Underground waters of eastern United States, M. L. Fuller, geologist in charge: Water-Sup. and Irr. Paper No. 114, 1905.
Two unusual types of artesian flow, by Myron L. Fuller: Water-Sup. and Irr. Paper No. 145, 1905, pp. 40-45.
Water resources of the Portsmouth-York region, New Hampshire and Maine, by George Otis Smith: Water-Sup. and Irr. Paper No. 145, 1905, pp. 120-128.
Field measurements of the rate of movement of underground waters, by Charles S. Slichter: Water-Sup. and Irr. Paper No. 140, 1905.
Observations of the ground waters of the Rio Grande Valley, by Charles S. Slichter: Water-Sup. and Irr. Paper No. 141, 1905.
For other reports see Water-Supply Paper No. 67 and Fifth and Nineteenth Annual Reports.

LAWS RELATING TO UNDERGROUND WATERS.

Relation of the law to underground waters, by D. W. Johnson: Water-Sup. and Irr. Paper No. 122, 1905.

WELL-DRILLING METHODS.

The California or "stovepipe" method of well construction, by Charles S. Slichter: Water-Sup. and Irr. Paper No. 110, 1905, pp. 32-36.
For other reports see Water-Supply Paper No. 101 and Bulletin No. 212.

MEASUREMENTS OF FLOW AND HEAD.

Approximate methods of measuring the yield of flowing wells, by Charles S. Slichter: Water-Sup. and Irr. Paper No. 110, 1905, pp. 37-42.

Field measurements of the rate of movement of underground waters, by Charles S. Slichter: Water-Sup. and Irr. Paper No. 140, 1905.

A convenient gage for determining low artesian heads, by Myron L. Fuller: Water-Sup. and Irr. Paper No. 145, 1905, pp. 51-52.

LISTS OF WELLS AND BORINGS.

Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch: Bull. No. 264, 1905.

Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller: Water-Sup. and Irr. Paper No. 102, 1905.

Preliminary list of deep borings in the United States, second edition, with additions, by N. H. Darton: Water-Sup. and Irr. Paper No. 149, 1905.

DRAINAGE OF WET LANDS BY WELLS.

Drainage of ponds into drilled wells, by Robert E. Horton: Water-Sup. and Irr. Paper No. 145, 1905, pp. 30-39.

SIGNIFICANCE OF THE TERM "ARTESIAN."

By Myron L. Fuller.

INTRODUCTION.

The term artesian, derived from the town of Artois in France, where the first flowing wells of importance were secured, was originally applied only to those wells in which the water rose above the surface, but in late years has been used in a number of other senses. At the present time, in fact, one can not be assured of its meaning in a particular paper unless its use is specifically stated. In many cases, fortunately, it is so defined, but the variability of the usage in different cases is sufficient to emphasize the need of a standard definition which shall be adhered to in public discussions.

It is doubtful if any definition can be devised which will meet the approval of or be accepted by all geologists, as opinions will naturally vary greatly according to the locality and nature of the work on which the geologists are engaged. But while there is considerable diversity of practice there is nevertheless a general tendency to give the term one or the other of two meanings, and a considerable number of geologists have expressed their willingness to accept any definition agreed on by the majority of active workers on underground-water problems.

The need of uniform practice has probably been felt most severely in the United States Geological Survey, where a considerable number of men devote their entire time to underground-water investigations and to related geologic problems, and it has become desirable either to drop the use of the term entirely or to adopt some definition which will meet the needs of geologists and be in harmony with the best usage in this country. For the purpose of obtaining the views of the different authorities, circular letters were mailed to those who have at one time or another been engaged in underground-water investigations or who are at the head of organizations such as State surveys, etc. Replies were received from about fifty geologists, and although they showed a considerable range of opinion, they were of much assistance in the consideration of a definition of the term.

USE OF TERM "ARTESIAN."

ORIGINAL USE.

The question of the early use of the term has been admirably summarized by W. H. Norton.[a] The word is derived from Artesium, the Latin equivalent of Artois, the name of an ancient province of France now included in the department of Pas de Calais, where the first flowing wells to be extensively known were obtained. The term in its etymology carries no definition, but it is unquestionable that it was the overflow of the Artois wells which attracted attention to them. The water in all wells, except those sunk to the shallow unconfined ground waters, rises when encountered and in many instances stands within a few feet or even a few inches of the top. Such wells, however, never, even in the earliest times, excited any comments, while flowing waters have almost invariably been regarded by the people at large as of some mysterious and unknown but none the less wonderful origin.

[a] Artesian wells of Iowa: Iowa Geol. Survey, vol. 6, 1897, pp. 122-128.

In the early days the term bored wells (puits forés) was practically equivalent to flowing wells, since these alone at that time were bored or drilled. Later the terms bored wells, deep wells, artesian wells, artesian fountains, and even bubbling wells have all been applied to the same type. As wide a range of terms is found in French scientific literature, viz, puits forés, puits artésiens, fontaines artésiennes, fontaines artificielles, fontaines jaillissantes des puits forés, etc. The term artesian obtained a definite place in literature as early as 1805, and was applied to those wells which flowed.

USE IN RECENT SCIENTIFIC LITERATURE.

As the geologic conditions governing artesian waters became known the term artesian was gradually extended by some writers to include any well in which the water rose under hydrostatic pressure when encountered, but others, especially teachers and authors of text-books, have continued to use the term in its original sense, while a few have used it to apply to deep wells in general. In addition there is a fourth popular use of the word for any tubular well regardless of depth or other factors.

The varying meanings given to the term in this country are shown by the results of an examination of underground-water papers by 25 American authors. By "artesian" 6, or 24 per cent, of these authors mean flowing wells; 15, or 60 per cent, wells in which water is under pressure but does not necessarily flow; and 4, or 16 per cent, deep wells in general. It should be borne in mind, however, that this is not altogether an expression of present practice. The use of the term artesian has, in fact, undergone a considerable change in the last few years, and a number of writers use it in a different sense at the present time from that adopted by them in their earlier writings. T. C. Chamberlin, for instance, at the time of the publication of his report on the requisite and qualifying conditions of artesian wells,[a] in 1885, defines an artesian well as a flowing well, but in the recent text-book of Chamberlin and Salisbury the statement is made that the term is now applied to any deep bored or drilled well.

EUROPEAN USE.

As to the European use of the term artesian the following quotation may be given from the letter from C. S. Slichter, who is probably more familiar with foreign literature on artesian waters than any other from whom replies to the circular have been received. "I have found very little difference of opinion among European writers in the use of the term. Any area in which the ground water exists under an appreciable pressure is called an 'artesian' area, and wells drilled in such a water-bearing medium are called 'artesian' wells. If they flow, they are called 'flowing' wells; if not, they are called 'nonflowing' wells."

PRESENT USE.

Preferences of scientists.—The preferences as to the use of the term artesian by the geologists from whom returns were received are summarized in the accompanying table (p. 11). The figures do not in all cases express the original preferences of the geologists, several having modified their opinions since the question has been under discussion. This is especially true in regard to the administrative heads and geohydrologists who, after a full discussion of the question, were nearly unanimous in favoring the use of the term for all waters under hydrostatic pressure and for all wells in which the water rises. The table therefore represents the present views of the geohydrologists of the Geological Survey and the Survey geologists interested in underground-water investigations, and the views as expressed in replies to the circular letter of inquiry sent to geologists outside of Washington. From expressions in these replies it is believed that a considerable number of others would now accept the use of the term for all hydrostatic wells. This is especially true of those who were inclined to drop the term, there being relatively little difference in the opinions of the two classes.

[a] Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 125-173.

Classified opinions relating to use of word "artesian" as applied to wells.

From—	Drop term artesian.	Flowing wells.	All wells in which water rises.	Any deep wells.
Administrative heads who are also engaged in field work on underground waters	0	1	4	0
Geohydrologists devoting entire time to underground-water problems	0	1	6	0
Geologists, other than teachers, who have had experience in underground-water investigations	5	3	9	1
Teachers with extensive field experience in underground-water investigations	1	5	4	1
Teachers with limited field experience in underground-water investigations	2	2	2	0

PER CENT FAVORING THE VARIOUS PROPOSED USAGES.

		Drop term artesian.	Flowing wells.	All wells in which water rises.	Any deep wells.
Mainly field experience	Administrative heads	0	20	80	0
	Geohydrologists	0	14	86	0
	Geologists with extended field experience	28	17	49	6
Field and teaching experience	Teachers with extensive field experience	9	46	36	9
Mainly teaching or theoretical experience	Teachers with limited field experience	33	33	33	0

In the above classification the figures do not possess the full significance they would have if a larger number of individuals were represented, but as the views of practically all those who have been engaged to any extent in underground-water problems are represented the figures may be accepted as illustrating the general trend of opinion.

It will be seen that in general the proportion of those favoring the restriction of the term artesian to flowing wells varies inversely with the amount of their actual field experience, although there are some variations inside of the main divisions of the classification due to differences in the standpoint from which the question is viewed.

The administrative heads, including State geologists and the geologists in charge of the eastern and western sections of hydrology of the United States Geological Survey, who meet the problem both in the field and in the office, or, in other words, who are familiar with both the field problems and the problems of logical treatment in reports, favor in the proportion of 4 to 1 the more extended use of the word.

Of the geohydrologists, or those devoting their entire time to the study of underground waters, only 1 out of 7 favors returning to the original definition of the term, while of geologists not devoting their entire time to underground-water work, but who have had extended experience with water problems, only 3 out of 18 favor returning to the original definition.

In the class of teachers the effect of their characteristic methods of thought is at once apparent, the percentage of those favoring the original use of the term artesian jumping to 46 per cent among those with extensive field experience and to 33 per cent among those with limited field experience in underground-water investigations.

Popular use.—The popular use of the term artesian is even more variable than the use by scientists. As pointed out in the letter of T. C. Chamberlin, there were not many flowing wells in the eastern portion of the country twenty-five years ago, and there was at that time no dominant practice, but "with the multiplication of wells and the growth of speech and common literature relative to them usage has drifted strongly toward the application of the term artesian to deep wells quite irrespective of the rise or flow of water, and it seems useless to try to stem the tide of this growing practice. It is easy to see how this arises and how inevitable it is. An individual or a community in considering

the question of sinking a deep well in hope of a flow naturally uses the term artesian in reference to the proposed well. The drillers do the same, and the name thus becomes fixed before the result is determined. Many wells are now designated artesian solely for the hygienic implications of the term."

The uses mentioned by Professor Chamberlin are widely prevalent throughout the eastern United States and often in those areas in the West in which flowing wells are absent. In general the term artesian is used for flows in those areas where flowing wells are common, but elsewhere the other usage predominates. The use of the term in various parts of the country, as brought to light by the work of the division of hydrology, may be summarized as follows:

Summary of popular use of term "artesian."

Locality.	Use of term.	Authority.
New England	Any deep well entering rock beneath the drift	M. L. Fuller.
Atlantic and Gulf Coastal Plain.	Any deep wells and those shallow wells which flow. Occasionally also for a shallow tubular well.	Do.
Piedmont Plateau	Any deep well	Do.
Paleozoic areas	Variable, but generally for any deep drilled well obtaining water (not oil or gas).	Do.
Great Lakes region	Any deep rock well drilled for water. Term not always applied to drift wells even when flowing.	Do.
Great Plains	Generally flowing wells	N. H. Darton.
Great Basin	Generally flowing wells, always in flowing-well districts.	G. B. Richardson.
Pacific coast	Generally for flowing wells	W. C. Mendenhall.

Summary of present use.—From the preceding discussion it is clear that no definite meaning can be assigned to the word artesian in a publication unless a definition is given in the same paper, a fact which is emphasized by the various ways in which the term is used, even the same writer sometimes employing it differently in different publications. The predominant scientific usage, as brought out by the table on page 11, is for all wells in which the water rises; in other words, for those exhibiting the hydrostatic or artesian principle. In popular practice it is applied, in addition to the uses previously mentioned, to deep wells in general, especially those in rock, and to a certain extent to any drilled wells yielding water of good sanitary quality.

ARGUMENTS FOR VARIOUS USES.

DEFICIENCY OF TERMS.

In artesian-water reports several types of wells and waters occurring under a variety of conditions must, in many cases, be constantly referred to. Of these, the most common are: (1) Unconfined waters, (2) confined waters, (3) hydrostatic principle, (4) hydrostatic basin, (5) nonhydrostatic wells, (6) nonflowing hydrostatic wells, and (7) flowing wells.

The term ground water is commonly used for the unconfined portion of the underground-water body, the top of which is represented by the water table, while the term flowing wells can be satisfactorily applied to those wells in which the water rises above the surface. On the other hand, the term nonflowing is not sufficient to express the character of a well in which the water rises but does not flow, as it does not distinguish between such wells and wells drawing from the water table.

The original use of the term artesian, as has been seen, was for flowing wells, but if restricted to such wells it can not be logically applied to basins in which the water is under pressure, but which do not yield flowing wells, nor can it be used to distinguish confined waters from the ordinary unconfined ground waters, the top of which is represented by the water table, or for the general result of the action of the hydrostatic principle.

SUMMARY OF ARGUMENTS.

Most of the arguments urged for the different uses of the term have been outlined or suggested in the preceding pages, but a brief statement summarizing them may not be out of place.

Use of term for flowing wells.—The arguments brought forward by those favoring the use of the term for flowing wells are—

(1) The term artesian was first used for flowing wells, and hence such use has priority over all others.

(2) The advocates of this usage believe that it is the predominating scientific use.

(3) They believe it likewise predominates in popular usage.

(4) The term is capable of precise definition and is based on conditions apparent to the layman as well as to the scientist.

(5) It is argued that the term is applicable and necessary for the practical discrimination of flowing and nonflowing waters, a distinction regarded as of great economic importance.

Use for well waters under pressure.—The advocates of the use of the term artesian for wells in which the water is under hydrostatic pressure present the following arguments:

(1) The definition given to the term should agree with the most common usage.

(2) The common European use of the term is for wells in which the water is under pressure, but which do not necessarily flow.

(3) The proposed usage is followed by the majority of field investigators in America.

(4) It is impossible at the present time to return to the original meaning.

(5) The term artesian, if used at all, should be applied to the hydrostatic principle and not to flows which are an accidental result.

(6) The term flowing describes the well exactly and in terms which can not be mistaken, making it unnecessary to restrict the term artesian to such wells.

Use for deep wells.—Those favoring the application of artesian to deep wells in general advance the following considerations:

(1) Depth and not flow was the significant feature of the original wells at Artois.

(2) Such definition of the term is according to popular usage.

DISCUSSION OF ARGUMENTS.

Original use of term.—All geologists, with one possible exception, are agreed that the original significance of the wells at Artois was their flow and not their depth, the fact that they were sunk in rock, nor the fact that they were drilled instead of dug. It can therefore probably be accepted as a fact that the term was originally applied to flowing wells (see pp. 9–10).

Predominant usage.—It has been shown (pp. 10–11) that although scientific practice varies considerably, the majority of geologists, including the European ones, use the term in the modified sense as applying to the hydrostatic principle and basin, and to wells in which the water rises. The popular usage is so variable that it would seem as if little would be gained by conforming to it, even if some one use largely predominated, which, however, is not the case.

Precise definition.—The term artesian, whether applied to all wells in which the water rises or only to flowing wells, is equally capable of precise definition, since a rise of the water is as positive a fact as is the flow, hence no argument can be based upon such preciseness of definition.

Necessity of term artesian for flowing wells.—That some term is necessary for designating flowing wells will be admitted by all, but that this must necessarily be the word "artesian" is very doubtful. Any word which will express the meaning will answer and the term flowing has an advantage over artesian in that it is self-explanatory.

Impossibility of returning to original meaning.—That it is probably impossible to return to the original meaning of the word artesian, except perhaps by scientists, will be recognized

by everyone. It will, however, doubtless be equally impossible to secure the uniform adoption of any other definition, so this argument can not be advanced in favor of any of the proposed uses.

Basis of nomenclature.—A definition of the term artesian, if it is to be redefined, should, it is believed, be based on a fundamental principle rather than on accident. The rise of the water in wells is the result of the action of the hydrostatic principle, which results from well-defined properties of liquids and definite physical laws, the rise taking place in all wells regardless of kind, size, depth, material, or location, provided only that confined waters are encountered. Flows, on the other hand, depend on the location. One well may flow and another on land a few inches higher may not flow. Again, a well may not rise to the level of the surface, but may yield flows when piped laterally to a slightly lower level.

TERMS TO BE SELECTED.

NATURE.

To secure the best results it is believed that certain principles should be assumed as a guide in the selection of terms. These are briefly outlined as follows:

(1) The question of depth should not enter into the probable nomenclature.

(2) Definitions should, if possible, be based on principle and not on accident.

(3) The terms should be scientific and should be capable of accurate definition.

(4) Provision should be made for terms for the hydrostatic basin and principle.

(5) The terms should meet the needs of the greatest possible number of workers

PROPOSED DEFINITIONS.

Along the line sketched in the preceding pages, the replies received from other geologists being considered, the terms to be used were thoroughly discussed by the members of the division of hydrology at the Survey, as a result of which the following definitions were agreed on with practical unanimity as the most expedient at the present time:

Artesian principle.—The artesian principle, which may be considered as identical with what is often known as the hydrostatic principle, is defined as the principle in virtue of which water confined in the materials of the earth's crust tends to rise to the level of the water surface at the highest point from which pressure is transmitted. Gas as an agent in causing the water to rise is expressly excluded from the definition.

Artesian pressure.—Artesian pressure is defined as the pressure exhibited by water confined in the earth's crust at a level lower than its static head.

Artesian water.—Artesian water is defined as that portion of the underground water which is under artesian pressure and will rise if encountered by a well or other passage affording an outlet.

Artesian system.—An artesian system is any combination of geologic structures, such as basins, planes, joints, faults, etc., in which waters are confined under artesian pressure.

Artesian basin.—An artesian basin is defined as a basin of porous bedded rock in which, as a result of the synclinal structure, the water is confined under artesian pressure.

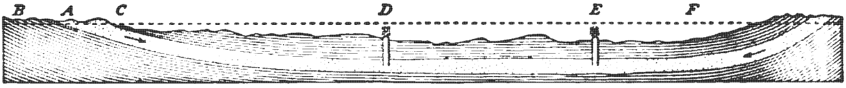

FIG. 1.—Conditions in an artesian basin.

Artesian slope.—An artesian slope is defined as a monoclinal slope of bedded rocks in which water is confined beneath relatively impervious covers owing to the obstruction to

its downward passage by the pinching out of the porous beds, by their change from a pervious to an impervious character, by internal friction, or by dikes or other obstructions.

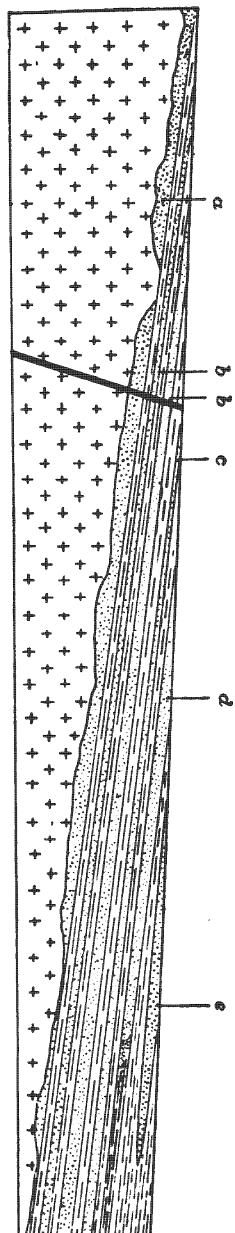

Fig. 2.—Possible conditions in an artesian basin slope. *a*, Water bed cut off by unconformity; *b*, beds cut off by dike; *c*, bed in which friction is the only obstruction to downward motion; *d*, porous bed changing to impervious; *e*, bed pinching out.

Artesian area.—An artesian area is an area underlain by water under artesian pressure.

Artesian well.—An artesian well is any well in which the water rises under artesian pressure when encountered.

REPRESENTATION OF WELLS AND SPRINGS ON MAPS.

By MYRON L. FULLER.

INTRODUCTION.

In general there has been no attempt at uniformity of practice in the delineation on maps of underground-water features or of wells or springs, but the increase in the number of men engaged in underground-water investigations both on local and national surveys and the increasing number of reports issued has been so rapid within the past two or three years that it now appears desirable that a concerted movement be made to develop a uniform system of symbols for use on maps. As by far the greater portion of the underground-water literature, other than that in engineering magazines, is published by the United States Geological Survey, it is thought that the adoption of some such system by its members will go far toward securing uniformity in the country as a whole.

GENERAL CONSIDERATIONS.

It is believed that the various types of wells and springs can be best shown by symbols of different colors, but unfortunately colored maps can not always be had, and it becomes necessary to represent a considerable number of features in black and white. Symbols which can be readily and quickly made are also a great convenience in note keeping in the field and result in much saving of time.

The number of symbols devised should be sufficient for the representation of all features which it is desirable to show. If wholly arbitrary devices are used, confusion will result whenever a considerable number are used simultaneously, but this difficulty will be largely avoided if the system adopted is based on a few suggestive forms grouped according to easily remembered principles. Unnecessary duplication should of course be avoided, although even a multiplicity of symbols leads to less confusion than the attempt to use a single device to represent several different things.

The older generalized maps, such as the early topographic sheets of this country, have given place to maps in which the features are shown in great detail, yet not only are the maps not crowded and confusing, but their usefulness has been increased many fold. It is believed that the use of any necessary number of symbols will likewise add to the usefulness of underground-water maps. The system should in fact be as nearly complete as is practicable, for although the use of many symbols on a single map might be objectionable, in reality only a few would, in most cases, be used at one time.

The principles to be considered in devising a system of well and spring symbols for underground-water maps are (1) simplicity, (2) clearness, (3) ease of making, and (4) suggestiveness. Failure to answer these various requirements ruled out many of the arbitrary systems used in the past, although several of the old symbols have been utilized in the new system proposed.

SYMBOLS.

It is believed that a system of symbols can be most logically developed if a single arbitrary device is taken as a base. In common practice a circle is most often used for a well, while more or less closely allied devices are used for springs. Inasmuch as both wells and springs are ordinarily approximately circular, this device, which seems to have both the required simplicity and suggestiveness, is proposed.

WELL SYMBOLS.

Base symbol.—The cross section of all but a few shallow open wells being circular, the unmodified circle is proposed as a base symbol to indicate all wells.

Successful and unsuccessful wells.—The most significant feature of a well from the economic and practical standpoints is its success or failure, and provision for its representation has to be made at the very start. It is thought that a successful well—a "full" well in many instances—can be best shown by a filled circle, or rather a circular dot, while an empty or unsuccessful well can be best shown by a simple circle.

Nonmineral and mineral wells.—Next to obtaining water its quality is most important and it becomes necessary to devise a symbol for indicating the mineral property. If an ordinary nonmineral well is represented by a circle, a mineral well, or one in which the water includes mineral matter in solution, may well be represented by a circle inclosing a dot.

Hydrostatic pressure in wells.—Next to quantity and quality the problem of whether or not the waters will rise is of the greatest importance, and a further symbol for distinguishing the wells simply sunk to the water table and in which the water does not rise from those sunk to confined or artesian waters becomes necessary. It is thought that a vertical line can be best used to designate the vertical rise of the water. Such a line, to be superimposed on any of the other well symbols, is therefore recommended.

Flowing wells.—The wells in which the waters rise are still further subdivided into those which fail to reach the surface and those which flow. For the latter the plus sign has often been used and is proposed in the present instance. It is to be superimposed on other well symbols as in the case of the vertical line.

Wells from different horizons.—In many areas all of the successful wells do not draw from the same horizon, in some instances as many as four or five different water-bearing beds being utilized. As no limit can be put to the number of horizons which it may be necessary to indicate, and as the horizons do not necessarily have any relation to the character of the well it has not seemed desirable to devise symbols for their representation. Instead it is recommended that the horizon of the supply be indicated by letters placed to the left of the well symbol, the space to the right being left for the insertion of figures giving the depth, height of water, elevation, etc.

SPRING SYMBOLS.

Base symbol.—As a base symbol for springs a circle with a short irregular line, indicative of a stream, leading away from the circumference, is considered as most in harmony with common usage, especially in topographic maps. All springs yield water, so there is no demand for distinguishing springs as in the case of successful and unsuccessful wells.

Mineral and nonmineral springs.—The presence of mineral matter in the water may be indicated by a dot placed in the center of the circle as in the case of the wells.

Superficial and artesian springs.—In some springs the water is unconfined, the flows taking place where the surface of the water table is cut by a depression. The movement of the water in such instances is almost entirely downward, and the springs are frequently spoken of as superficial or gravity springs, since the water has not been to any distance below the water table and emerges under the direct action of gravity. The water of such springs will not rise if confined. In artesian springs, on the other hand, the water comes from below and rises under the influence of hydrostatic pressure, and when confined will sometimes rise to considerable heights above the spring mouth. In such instances it is recommended that, as in the case of the wells, the hydrostatic principle be represented by a vertical line superimposed on the base symbol, but not extending beyond the circumference of the circle. Flows do not need to be represented, since all springs possess this property.

Thermal property.—Springs may be further divided into cold or warm, but only one symbol, that for the thermal property, is required. For this a horizontal bar is proposed

as the simplest device which can be superimposed on all others. It is intended that this bar shall not extend beyond the circumference of the circle so that there may be no confusion with the device indicating flowing wells.

SUMMARY.

Base or primary symbols.—As primary symbols the following devices are proposed:

= well.

= spring.

Secondary symbols.—The secondary symbols to be superimposed on the primary symbols are six in number:

= water (for wells only).

= mineral property.

= waters which rise.

= waters which flow (for wells only).

= thermal waters (for springs only).

Application.—The use of the various devices is illustrated below. The arrangement is not intended as a classification of wells and springs, but is simply for convenience in showing the use of the symbols.

Wells	Successful	Nonmineral	Rise	Flowing
				Nonflowing
			No rise	
		Mineral	Rise	Flowing
				Nonflowing
			No rise	
	Unsuccessful			
Springs	Nonmineral	Artesian	Cold	
			Warm	
		Gravity	Cold	
	Mineral	Artesian	Cold	
			Warm	
		Gravity	Cold	

OCCURRENCE OF WATER IN CRYSTALLINE ROCKS.

By E. E. Ellis.

INTRODUCTION.

While the laws governing the occurrence of ground water in unconsolidated materials and in porous sedimentary formations are now generally understood, little has been written concerning the sources of supply for wells in the so-called crystalline rocks. For this reason, when an opportunity was presented in connection with an investigation of the underground waters of Connecticut, special attention was given to the occurrence of water in such rocks.

The term "crystalline" is applied to rocks whose component grains have crystallized into their present relative positions; contrasted with them are the sedimentary types, which are laid down under water and which generally consist of fragments of older rocks mechanically arranged. Under the head of crystalline rocks two main types may be distinguished—igneous rocks, such as granite, diabase, gabbro, granodiorite, etc., which were once in a molten condition, and crystallized and consolidated on cooling; and metamorphic rocks, such as schists and gneisses, which were originally either sedimentary or igneous, but have been altered by metamorphic processes to their present form. The Connecticut limestones, or marbles, are classed with the crystalline rocks.

It is the purpose of the present paper to call attention to some of the features of special economic interest, with the hope that they may be of value to those seeking for information as to the probabilities of success in drilling in similar regions elsewhere in New England or along the Piedmont Plateau to the south. All discussion of the literature of the subject and, so far as practicable, all local references are omitted, being reserved for the special detailed report on the occurrence of water in the crystalline rocks of Connecticut.

ROCK TYPES.

CRYSTALLINE ROCKS.

The principal types of crystalline rocks dealt with are granite, gneiss, and schist, although some diabase and limestone areas were studied. The granites, although of many varieties, are mainly of the ordinary somewhat coarsely crystalline types, consisting mainly of quartz, feldspar, and mica. The gneiss is more variable, but may be distinguished by the driller from the granite by its banded appearance. The granodiorite resembles ordinary granite, but is darker, frequently being known as black granite.

In the schists the banding is more highly developed, mica is present in large amounts, and there is a decided tendency to cleave into more or less flat fragments. Some of the schists, in which little mica is present, much resemble slate. Pegmatite, usually called

"feldspar" by the quarrymen and drillers, occurs as dikes or more irregular masses cutting the older rocks, and is usually recognized by its large crystals and white or light color. Diabase, or trap rock, may be distinguished by the driller from its crystalline character

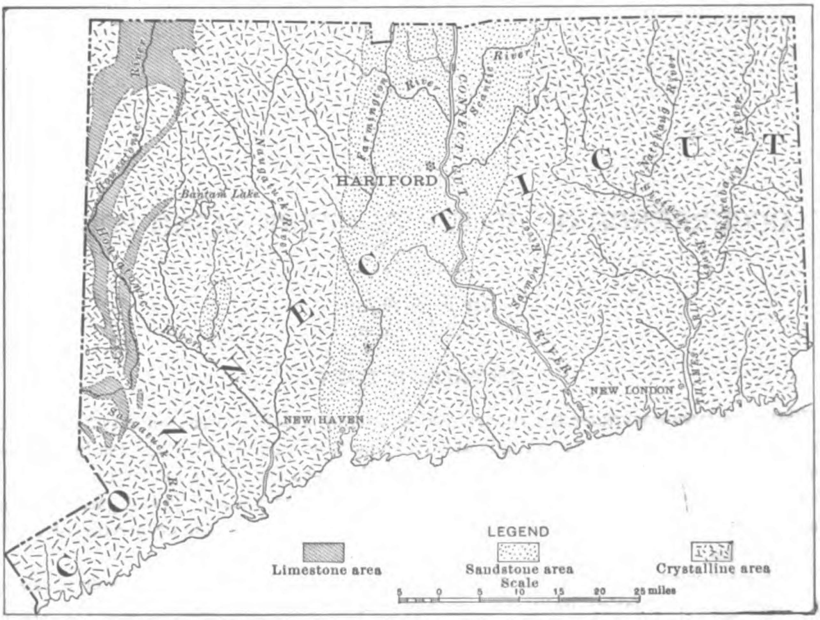

FIG. 3.—Geologic sketch map of Connecticut. The present paper deals with the crystalline and limestone areas.

and dark greenish-black color. The distribution of the crystalline rocks and limestones are shown in fig. 3.

DRIFT.

In the region under investigation the rocks are in large measure covered with deposits left by the ice sheet which once occupied the region, part consisting of a heterogeneous mixture of bowlders, sand, and clay known as hardpan or till, and part of stratified sand, gravel, and clay. The till is seen largely on the hills, averaging about 15 feet in thickness, while the stratified drift occurs mainly in the valleys, where it has an average thickness of about 36 feet. In general, therefore, the hills have a configuration corresponding rather closely to the underlying rock surface, the minor irregularities of which are masked by the overlying drift. On the other hand, the valley bottoms are flat and would show a decidedly different topography if the sand and gravel deposits were removed.

DRILLING PRODUCTS.

The marked characteristics of these rocks give equally characteristic products in drilling. In many cases fragments will be yielded by the drill which are large enough to show the general texture; in others the drillings will all be in the form of finely broken fragments. In general the granite drillings yield an even-grained product, with a large proportion of the white or pink minerals, quartz and feldspar, and maintain the same character and color of material for a number of feet. Gneiss gives a somewhat similar product, but will usually have a larger proportion of biotite, or black mica, and the character of the drillings will change rapidly, usually every few inches. Schist is generally softer and more readily drilled than either of the preceding types and the drillings contain a conspicuous amount of mica, which occurs in larger particles than the other minerals.

The drillings maintain a fairly uniform appearance, as in granite. Phyllite is usually a hard rock to drill, owing to its fineness of grain and the frequent nearly vertical position of its cleavage. Trap rock is considered the most difficult rock to drill, because of its hardness, and is readily distinguished. Limestone drillings are ordinarily white, and may be tested by adding acid or strong vinegar, which will produce an effervescence, owing to the escape of carbon-dioxide gas.

WATER IN CRYSTALLINE ROCKS.

OCCURRENCE IN PORES.

The occurrence of water in crystalline rocks is very different from that in sedimentary rocks, largely owing to the gréat difference in porosity. The sedimentary deposits, which are made up of fragments of older materials generally cemented into new rock, are commonly very porous and often absorb several per cent of their volume in water. (See table by M. L. Fuller, p. 61) Porosities of sandstone average about 15 per cent, shales about 4 per cent, and limestone 5 per cent. In granites and other crystalline rocks, however, the absorption is usually less than half of 1 per cent of the volume. The limestones here discussed have about the same porosity. In such rocks the water moves through the pores so slowly that it can never escape fast enough to be of value in wells. Fortunately there are in the crystalline rocks many large passages, some of which are described below.

OCCURRENCE IN JOINTS.

Joints are the more or less extensive and generally smooth and straight planes cutting the rock in various directions, and are the result of fracturing forces which have split it into blocks of different shapes and sizes, although usually without any appreciable separation or movement of the rocks.

TYPES OF JOINTS.

Vertical joints.—The most common type of joint is that having an approximately vertical position (70°-90°), but joints with many other inclinations occur. In the region investigated the character of the joints is as follows:

Inclination of joints in Connecticut rocks.

Inclination.	Number of localities observed.
80°-90°	40
70°-80°	17
74° (mean)	75
40°-70°	14
Below 40°	4

The joints are mostly straight, but a few that were curved or showed other irregularities were observed.

Horizontal joints.—In many of the rocks there is another class of joints which are very different from the vertical type, both in their degree of inclination and in their general nature. These occupy an approximately level position, rarely more than 20° from the horizontal, and usually much less than this. In general this joint structure follows the surface configuration of the rock, but occasionally is found to pitch at a low angle in a direction opposite to the slope of the hillside.

Fissility and schistosity openings.—The porosity of schist, while probably greater than that of slate, is too small to admit artesian circulation through the pores. In the crumpled schists there appear to be openings between the laminæ, but they probably do not permit sufficient rapid circulation for well supplies. It is upon the more or less pronounced

fracture planes parallel to the schistosity, especially those near the surface, that the wells depend.

Faults.—Faults may be considered as extreme types of joints in which there has been movement of one wall of the joint plane past the other. The work of Hobbs, Davis, and others has shown that there has been a considerable amount of faulting in Connecticut, while it is not uncommon to find strongly marked shear zones, indicating slipping in the crystalline rocks. They are comparatively rare phenomena, however, and are seldom encountered in well drilling, and accordingly will be treated simply as special cases of jointing. They are possibly important as sources for springs, although it is extremely difficult and generally impossible to ascribe any particular spring to a fault plane.

SPACING AND CONTINUITY OF JOINTS.

Vertical joints.—The vertical joints, which are the important water carriers, have no regularity of spacing even for the same rock. From a large number of observations it appears that at the places where jointing is well developed the spacing of all joints is commonly between 3 feet and 7 feet to a depth of 50 feet, the average spacing, however, between vertical joints of the same series for the crystalline rocks, excluding trap and limestone, is more than 10 feet for this depth, while the study of well records indicates that this is not far from the average spacing for all joints to a depth of 100 feet.

Although there are many exceptions, joints of this type are generally continuous for considerable distances both along the line of outcrop and that of dip. Faults, however, have the greatest continuity and frequently extend for several miles across the country, occasionally for tens of miles. The sheeted zones of close jointing are probably nearly as continuous as faults, and their dimensions should be measured in hundreds of feet. Where there is a well-defined parallel joint series the prominent joints may extend several hundred feet, while the minor intersecting joints will be much shorter.

Horizontal joints.—There is much greater regularity of spacing in the horizontal joints than in the vertical joints. They are apparently surface phenomena and diminish in number rapidly with depth, and it is probable that they do not exist as fractures at 200 feet below the surface. In the first 20 feet below the surface these horizontal joints average 1 foot apart, in the next 30 feet they average between 4 and 7 feet, and in the next 50 feet they are much more widely spaced, running from 6 to 30 feet or more apart.

The continuity of individual horizontal joints rarely exceeds 150 feet, but owing to their intersection of each other a continuous opening might be formed of several hundred feet which would be in the form of a curved sheet approximately parallel to the hill slope, each lower sheet having less curvature than the other. They are probably better developed on the hills than in the valleys, as the pitch of the joints is usually less than the slope of the surface, which consequently cuts across the joints; and as they are wider spaced with depth the horizontal joints which cross the valleys will be widely spaced.

DEPTH.

Not only do joints become tighter with depth, but they are farther apart. The application of this principle in the drilling of wells is of the utmost importance, as it is frequently asserted that water can always be obtained by going deep enough, whereas, in fact, the deeper the well the less the chance of striking fractures, which are the only passages permitting water transmission in crystalline rocks. It is further evident that, owing to the closing of joints with depth, there will be a much greater circulation in the upper half than in the lower half of any individual joint.

The number of fractures supplying water varies greatly in different wells. In some cases the greater part of the water appears to come from a single opening, while in others the water comes in slowly from a large number of openings. In the average well there are from one to four horizons from which the principal supplies of water come, although the yield from one of them is usually greater than from all the others together. This is particularly true of

the deeper wells (from 200 to 300 feet), in which the principal source is usually very close to the bottom of the well.

If an average inclination of 70° from the horizontal and an average spacing of 10 feet be assumed for the vertical joints for the upper 200 feet of rock, each well 200 feet in depth will intersect seven joints. This is probably not far from the average for all the wells, the small and discontinouus fractures near the surface being neglected. Below 200 feet the average number of joints intersected would be somewhat decreased for the next 100 feet, and greatly decreased at depths greater than 300 feet.

INTERSECTION OF JOINTS.

The intersection of joints with one another is very important in determining the nature of the underground circulation. While all joints intersect, the circulation is greatest where the joints of the principal systems meet and where, in addition to the vertical joints, horizontal fractures occur.

WIDTH OF OPENINGS.

At the immediate surface, joints often have an opening of one-half inch to 2 inches and occasionally much greater. This wide opening is due to various weathering and mechanical agencies, which act only near the surface, and consequently is not found at depths below which these agents act. In an artificial cut, such as a quarry wall, joints which may be open one-half inch at the surface are often found to be too tight to admit a knife blade at 25 feet below the surface.

While the joints at 30 feet below the surface may have only one-twentieth the opening that they have at the surface, the same proportionate tightening will not continue at lower depths, although it is certain that the greater the depths the greater must be the tendency of joints to close, owing to increased pressure and the smaller opportunity for lateral expansion below the level of minor topographic relief.

QUALITY OF THE WATER.

The waters of the crystalline rocks are variable in mineral composition, but in most instances are relatively soft, the carbonates or sulphates of calcium or magnesium being present only in small amounts. They are practically always safe for domestic purposes and give little trouble in boilers. Some wells on islands or very near the coast on the mainland yield brackish water.

WELLS.

VARIABILITY OF CONDITIONS.

In crystalline rocks it is impossible to foretell the conditions that will be encountered in a well, since these often depend on the occurrence of joints of which there may be no indication at the surface. One well may be entirely different in both the quantity and quality of its waters from another only a few feet away. It is not therefore advisable for a driller to guarantee water unless an additional charge is made to insure him against risk of failure.

Among 237 wells of which information was secured only 3, or 1¼ per cent, failed to get water, and although there is a general reluctance to give information in regard to such wells, the probabilities of failure are probably not more than one in twenty. It should be remembered, however, that this applies only to domestic wells, and that the chance of failure when large supplies for manufacturing or similar purposes are demanded is considerably greater. It is probable, however, that 90 per cent of the wells sunk have obtained supplies sufficient for the use required.

FLOWING WELLS.

Although wells in which the water rises above the rock surface are common, very few instances where it reaches the surface of the overlying drift are known. Only six yielding permanent flows have been reported, although a number of others flowed for a few minutes when first drilled. All of the flowing wells are located on slopes with considerably higher

elevations near by, and are generally found only where there is a considerable thickness of drift resting on the rock surface and serving to confine the water in the rock.

The flows are ordinarily of no especial value if the water is to be utilized at the well, as the rise above the surface is very slight. In some instances, however, when the wells are on hillsides, the water can be piped to a point lower down, giving a continuous flow without pumping. Flows can occasionally be obtained by the use of siphons when the water is within 30 feet of the surface and the point where the water is used is more than 30 feet below the mouth of the well.

WATER SUPPLY.

GENERAL STATEMENT.

The yield of a well depends on its depth, its topographic location, and the nature of the rock in which it is made.

As previously stated, only 3 out of the 237 wells reported were completely dry. Only 17, or 12½ per cent, furnished less than 2 gallons a minute. About 15 gallons a minute is the average yield, although some yield over 30 gallons a minute on continuous pumping. They are remarkably constant, showing little variation in yield, either annually or through a period of years. Some have shown increased and others decreased yields, but generally the change is inappreciable. The level to which the water rises is nearly as unchangeable as the yield, usually being little if at all affected by dry seasons. Generally the water regains its original level very quickly after pumping has ceased, although in some wells it returns very gradually.

Some details are given in the following table:

Yield in gallons per minute at various depths (beneath surface covering) in various types of rock.

Depth below surface covering (feet).	Schist.		Granite.		Gneiss.		Granodiorite.		Quartzite schist.		Total.	
	No. of wells.	Yield.	No. of wells.	Yield.	No. of wells.	Yield.	No. of wells.	Yield.	No. of wells.	Yield.	No. of wells.	Yield.
0- 30	2	3.2	1	7	1	1.0					4	3.6
30- 50			9	6.7	13	11.9					22	9.75
50- 70	4	9.5	5	9.8	14	12.4					23	11.3
70- 90	3	21.6	2	20.5	7	7.6	1	8.0	1	6.0	14	12.4
90-110	6	22.1	8	14.4	2	5.5	1	0			17	15.2
110-200	2	8.5	5	13	8	8.3	6	46			21	20.2
200-300			3	16	2	33.0	3	12.7	1	0	9	16.7
300-400			1	0	2	22.0	1	2			4	11.5
400-500			1	0	1	50					2	26
500-650					2	14			1	2	3	5.2

There is, in general, a slight increase in the yield of water with increased depth from 15 feet down to 200 feet, beyond which the chances decrease, wells over 400 feet being in many cases failures. The results of observations on the latter class are summarized in the following tables:

Yield of wells over 400 feet deep.

Location.	Depth.	Yield per minute.
	Feet.	*Galls.*
Valleys	583	25
	690	10
	503	26
	425	50
Hills	850	40
	548	Small.
	420	2
	485	Dry.
Slopes	610	12
	645	4
Island	1,465	[a] 3

[a] Salty.

The average depth in rock of 163 wells is 88.8 feet and the average total depth, including the surface material overlying the rock, is 108.4 feet. Ninety per cent of the wells are less than 300 feet in depth and 82 per cent less than 200 feet in depth. In many of the wells which have gone below 250 feet the main and in several cases the entire supply has come from seams at less than 250 feet in depth. From a study of the recorded wells it would appear, therefore, that if a well has penetrated 250 feet of rock without success the best policy is to abandon the place and sink in another location. In the case of wells in granodiorite which have been successful at an average greater depth than in other rocks this depth might be somewhat too small, while in other rocks it is very possible that a maximum depth of 200 feet should be adopted.

The following table summarizes the depths of the wells under 400 feet and the proportions of each in rock and drift:

Average depths of surface material and of the entire well, exclusive of wells over 400 feet in depth and of wells known to be dry.

Position.	Average thickness of drift.	Average depth in rock.	Average total depth.	Number of records.
	Feet.	*Feet.*	*Feet.*	
Valleys	36	104.5	140.5	26
Hills	17	94.0	111.0	67
Slopes	21	79.4	100.4	54
Plains	10	74.0	84.0	16

The average total depth of the 163 wells is 108.4 feet.

TOPOGRAPHIC LOCATION.

It has been found that on an average water is encountered in the crystalline rocks at a less depth on the hills than in the valleys, but this is due largely to the heavier deposits of drift that must be penetrated before rock is reached in the valleys.

Average depth from surface to water level.

Position.	Depth to water.	Number of records.
	Feet.	
Hills	19	76
Valleys	11	30
Slopes	15	44
Plains	8	30

The average yield of the wells in the valleys is, however, somewhat greater. Wells on the slopes for some reason have an average yield of less than one-half that of those in either of the other locations.

Average yield of wells in various locations.

Location.	Yield per minute.	Number of records.
	Galls.	
Valleys	24.4	18
Hills	20.5	27
Slopes	8.7	25
Plains	18.8	9

Some rather puzzling features are brought out by the following table, showing the relation of the water level to the level of the rock surface (bottom of overlying drift) in wells in various topographic locations:

Relation of water level to surface of rock (bottom of overlying drift).

POSITION OF WATER LEVEL.

Material.	Topographic location.	Wells observed.	Below rock surface.	Above rock surface.	At rock surface.
			Per cent.	*Per cent.*	*Per cent.*
Hills	Granite		37	50	13
Valleys			11	89	0
Slopes			41	50	8
Plains			50	50	0
Hills	Schist		62.5	37.5	0
Valleys			0	100	0
Slopes			50.0	33	17
Plains					
Hills	Gneiss		69	21	10
Valleys			22	78	0
Slopes			44	36	20
Plains			0	50	50
Hills	Granodiorite		71	0	29
Valleys			0	100	0
Slopes			60	40	0
Plains			33	67	0

SUMMARY OF ALL WELLS.

Hills		42	61.9	26.2	11.9
Valleys		24	12.5	87.5	0.0
Slopes		35	48.5	40.0	11.5

It is seen that in nearly all valley wells, no matter in what kind of rock they may occur, the water is under artesian pressure and rises above the rock surface. In schists, gneisses, and granodiorites the percentage of wells on hills and slopes in which the water is below the rock surface is invariably and rather uniformly greater than those in which the water level is above the rock surface, the percentage ranging from 62 to 70. In the granites, on the contrary, exactly the opposite is true, the water failing to reach the rock surface only in 37 per cent of the wells. In other words, in hill wells the granite waters rise to the rock surface nearly twice as frequently as in the case of other rocks.

The situation of the wells with reference to the sea is very important, most of the wells which fail to get pure water being in fact located along the coast or tidal rivers. Wells within 100 feet of the sea are always liable to be spoiled by the entrance of salt water, while there are cases where the latter has penetrated to wells 500 feet distant. There are, however, exceptions to this rule, some good wells being obtained even close to the water. Much may depend on the amount pumped, as a well which yields fresh water when only a little water is used may become salty if heavily pumped. When a choice of location can be had a point as high and as far removed from the sea as possible should be selected.

NATURE OF ROCK.

The amount of water in a well depends to a considerable extent on the nature of the rock in which it is made, largely because of the greater frequency of joints in some rocks than in others. In general the yield from wells in granite, gneiss, and common schist does not vary greatly from 13 gallons a minute. In those in granodiorite, however, two and one-half times as much is obtained, in quartzite schist only about one-half as much, while in the slaty rocks the supplies are very small. The details are well brought out by the following table:

Yield of wells in various types of rock.

Material.	Depth of surface covering.		Depth in rock.		Total depth.		Yield.	
	No. of records.	Feet.	No. of records.	Feet.	No. of records.	Feet.	No. of records.	Gallons per minute.
Granite	45	20.6	45	102.5	54	122.5	35	13
Gneiss	69	16.3	70	112.6	73	131.4	50	12.3
Quartzite schist	3	32.5	3	411.0	3	443.5	3	7.25
Schist other than quartzite	23	13.7	23	96	23	109.7	16	13.9
Granodiorite	15	24.1	16	138.5	19	156.6	13	33
Phyllite (slate)	4	14.4	5	80.2	5	93.8	....	Very poor.

The drift plays a very important part in the occurrence of water in the crystalline rocks. When drift is absent over the catchment area the rain runs rapidly off the surface of the smooth, bare rock and little is absorbed, but when there is a considerable thickness of drift large amounts of water are absorbed by its porous materials and are regularly and continuously supplied to the underlying crystalline rocks through their joints. The importance of a drift mantle in affording conditions favorable to flows at the well sites has already been mentioned. It is apparent, then, that in general water will both be more abundant and rise to a higher level when the crystalline rocks in the catchment areas and at the wells are covered with drift than when they are bare. This is especially true when the drift occupies basinlike depressions in the rock surface.

COST OF WELLS.[a]

The cost of wells is very variable, depending on the diameter of the hole, whether the well is sunk by the day or by the foot, and whether or not a supply is guaranteed. Two-inch wells are the most common, and cost about $2 a foot for the wells under 100 feet in depth, $2.50 for wells between 100 and 200 feet, $3 for wells between 200 and 300 feet, and $3 to $4 for wells over 300 feet. The cost of a well drilled by the day will vary greatly according to the depth at which water is struck, but seems to average a little higher than by the foot. The cost when water is guaranteed is probably slightly higher than under either of the other methods. For wells of larger diameter the price is much higher. The average cost of 123 wells, averaging 108 feet in depth and yielding a mean of 12.7 gallons a minute, is $4.25 per foot.

SUMMARY.

The water of the crystalline rocks occurs, so far as it can be secured by wells, wholly in joints, faults, or other fracture openings, the pores and schistosity planes being too close to permit active circulation. The water seems to occur largely in the vertical joints or faults, especially in the sheeted zones consisting of numerous crowded fracture planes. In Connecticut a common spacing between the surface joints is 3 to 7 feet, but in some cases they are much farther apart. At depths of more than 50 feet the space becomes greater owing to the dying out of subordinate joints.

The spacing of the horizontal joints is rather regular. In the first 20 feet below the surface they average 1 foot apart, for the next 30 feet from 4 to 7 feet, and in the following 50 feet they are from 6 to 30 feet or more apart.

The most favorable points for water are at the intersection of two or more of the joint systems, the circulation often being concentrated at these points.

It is impossible to foretell the success or yield of a well in crystalline rocks, but the chances of a moderate supply are at least as good as 9 in 10. The character of the water obtained is in general excellent, both for domestic and manufacturing purposes, and is usually soft. Hills and places where the soil is thick are the most desirable locations for drilled wells. In general, it is better to abandon a well and seek a new location if not successful when a depth of 250 feet has been reached, as the possibilities of a supply below this depth are much less than at shallower depths.

[a] Data mainly by M. L. Fuller.

MAP OF FLOWING-WELL DISTRICTS OF EASTERN PART OF NORTHERN PENINSULA OF MICHIGAN.

FLOWING-WELL DISTRICTS IN THE EASTERN PART OF THE NORTHERN PENINSULA OF MICHIGAN.

By Frank Leverett.

GENERAL STATEMENT.

The flowing wells of the northern peninsula of Michigan are obtained in part from the Pleistocene deposits and in part from Silurian and Cambrian formations. The rocks dip southward toward the basins of Lakes Huron and Michigan and southeastward toward the Green Bay basin and the adjacent portion of the Lake Michigan basin. In consequence of this arrangement of the strata, water absorbed in the part of the peninsula bordering Lake Superior, which is as a rule an elevated tract, passes toward the basins of Lakes Huron and Michigan and Green Bay under sufficient hydrostatic pressure to yield flows at moderate elevations above the surfaces of these water bodies. Already flows have been obtained along the western side of Green Bay throughout its entire length, in wells ranging from 200 feet or less up to about 800 feet in depth. They have been obtained on Garden Peninsula, lying between Big Bay de Noc (at the northern end of Green Bay) and Lake Michigan. They have also been obtained along the northern shore of Lake Michigan at several points from Manistique eastward. On the borders of Keweenaw Peninsula there are also flowing wells from the Cambrian sandstones, but these are outside the district covered by the writer.

Wells from the drift have already been extensively developed in a low district lying north of the "Niagara" escarpment in Chippewa and Luce counties and on the western shore of Whitefish Bay at Emerson, and there are small areas in other parts of the peninsula where they are either already obtained or may be expected to be obtained.

Very little information could be secured from drillers or well owners concerning the character of the rock formations which yield flows. In most cases they report that the flows are obtained under a bed of rock, which was hard to penetrate with the drill, and which seems to have served as a cover to prevent the natural escape of the water. In some cases, as at Gladstone and other points along the western side of Green Bay, water is obtained at more than one horizon, but because of the meagerness of the data the writer did not attempt to work out the stratigraphy of these water-bearing beds. Some identifications made by Lane and by Alden appear in the Annual Report of the State Geologist for 1903.

The flowing wells obtained in the drift deposits usually penetrate a bed of clay and obtain water in sand or gravel. In Chippewa County the clay is a laminated, nearly pebbleless deposit, apparently laid down in the bed of a great glacial lake, Lake Algonquin, which covered this region after the retreat of the ice. But in Luce County the clay deposits are in some cases found to be stony, and are probably of glacial rather than lake deposition. Beneath the clay deposits of Chippewa County a bed of sandy material full of water generally occurs, but is not a good source for flowing wells, since it is too fine grained to furnish water rapidly. It is termed slush by the drillers, and it is their custom to continue through it to a bed of gravel.

In the division of the wells into districts (Pl. I) there is usually the probability that over part of the intervening territory the altitude is too high to permit flows. But in some cases further exploration may develop wells between districts now placed in separate groups. An attempt is made to indicate possible extensions of the flowing-well areas as well as their present limits. The districts are taken in order from east to west, those in the drift deposits being first considered and then those in rock.

FLOWING-WELL AREAS.

FLOWS FROM DRIFT.

McCARRON.

Two shallow flowing wells have been obtained in a ravine near McCarron post-office, Chippewa County, at an altitude of about 650 feet above tide. One at the residence of David McCarron in sec. 4, T. 45 N., R. 1 E., is 30 feet in depth and has a head of about 3 feet. The water is sulphurous and has a temperature of 45° F. About one-eighth mile northeast of the McCarron well, at the residence of Samuel Boyle, in sec. 34, T. 46 N., R. 1 E., is a well 37 feet deep, with similar head and quality of water, and a temperature of 44.9°. The temperatures were taken August 10, 1905, when the air temperature was 85° F. Both wells penetrate a laminated, pebbleless, red clay and enter a bed of gravel.

DONALDSON.

A flowing well was obtained in the autumn of 1905 at Donaldson, by Robert McKee, which was reported by the driller, Judson Daley, of Pickford, to be 78 feet in depth and to flow one-third gallon a minute. It is located in a ravine about 15 feet above a tributary of Charlotte River, at an altitude of about 650 feet, and penetrated clay to the gravel bed at its bottom. It lies in sec. 31, T. 46 N., R. 1 E., and is used as a public well.

McEVOY.

This is probably the oldest flowing well in Chippewa County, having been running for at least twenty-five years. It is located in sec. 14, T. 46 N., R. 1 W., on the Mackinaw road running from Sault Ste. Marie to St. Ignace. It stands in a slough tributary to Charlotte River, about 15 feet below the bordering plain at an altitude of 700 feet above tide. It has a depth of 45 feet and a head of about 5 feet or less above the surface. The well, which is said to have maintained its strength, yields over a gallon a minute.

PICKFORD DISTRICT.

The Pickford flowing-well district is a narrow strip along Munuscong River and its tributaries, in the vicinity of the village of Pickford, most of the wells being in Chippewa County, but a few in Mackinac County. Of the 32 wells already developed 26 are within the village limits. The outlying wells, however, seem to indicate that flows may be obtained from the junction of the two forks of Munuscong River northeast of Pickford for a distance of 5 or 6 miles up the west fork and 2 or 3 miles up the east fork. The water obtained is suitable for boiler use, there being only a moderate amount of lime present. It has a little iron and in some cases a slight sulphurous odor. The temperature of the water where not surface heated is 43.5° to 45° F., but in most cases the flow is so weak that it can not overcome the effect of the air on the portion of the pipe above the surface, nor of the warm soil around the upper portion of the pipe. The data contributed by Mr. Daley are from careful records in his notebook. They show an interesting variation in the thickness of the laminated red clay and the underlying sandy slush, the cause of which is not clearly understood. It is possible, however, that a change to more sandy texture may set in at 50 feet or less in wells where the driller has classified material as red clay to a depth of over 100 feet. In the table given below several wells are included which would not flow at the level of the ground, but are made to flow by being piped into cellars or basins below the surface.

Flowing wells at Pickford (T. 43 N., R. 1 W.).

Owner.	Location.	Driller.[a]	When made.	Altitude.[b]	Depth.	Diameter.	Flow per minute.	Head.	Temperature.	Section.			Remarks.
										Red clay.	Slush.	Gravel.	
				Feet.	*Feet.*	*Inches.*	*Galls.*	*Feet.*	*° F.*	*Feet.*	*Feet.*	*Feet.*	
A. Roe	Pickford	J. D.	1905	630	128	2	1.0	+3.5	46.2	80	34	14	
Central Hotel	....do	J. S.	1895	630	128	4	Strong.	....	....	80	34	14	Distribution system.[c]
J. Crawford	....do	J. D.	1904	630	128	2	....	....	43.5	80	32	14	
J. Cameron	....do	J. D,	1902	630	128	2	.25	....	46	80	40	8	
J. Robinson	....do	J. D.	1905	631	129	2	.10	+2	45	109	0	20	Sandy gravel.[d]
Geo. Wilson	....do	J. D.	1903	631	131	2	....	+3	50	107	0	24	Temperature in tank.
H. Miller	....do	J. D.	1901	635	127	2	....	−3	....	124	0	3	Roily water.
Creamery	....do	J. S.	1900	628	67	3	Strong.	....	....	....	....	....	Newly driven in 1900.[e]
D. Bacon	....do	J. D.	1903	632	127	2	....	....	....	119	0	8	
I. Watson	....do	J. D.	1901	625	88	2	.5	+6	46	45	40	3	
F. Green	....do	(?)	(?)	630	....	....	....	....	....	....	....	....	Flows in cellar.
J. O'Niel	....do	J. D.	1901	630	98	2	....	....	....	....	....	....	Flows in basement of store.
J. McDonald	....do	(?)	(?)	630	87	2	....	....	....	....	....	....	Flows in cellar.
F. Taylor	....do	(?)	(?)	630	89	2	....	....	....	....	....	....	Do.
J. Barton	....do	J. D.	1902	630	119	2	....	−1	....	....	....	....	Flows in tank.
D. Aldridge	....do	J. D.	1905	635	127	2	....	−3	....	....	....	....	Do.
S. Crawford	....do	J. D.	1902	620	87	2	....	+3	....	74	0	13	Strong flow.
D. Stevens	....do	(?)	(?)	625	95	2	....	+5	....	....	....	....	Weak flow.
H. Blair	....do	J. D.	1901	632	122	2	....	0	....	....	....	....	Gravel at bottom.
F. Johnson	....do	J. D.	1901	635	140	2	....	−1.5	....	120	13	7	Flows in tank; strong well.
Schoolhouse	....do	J. D.	1902	635	122	2	....	−4	....	102	0	20	Flows in basin.
F. H. Taylor	....do	(?)	(?)	614	87	2	.1	....	54	....	....	....	Well in ravine.
Chippewa Hotel	....do	I. M.	1895	630	126	4	....	+3	....	....	....	....	Flows in basin.

[a] J. D. = Judson Daley, professional driller, Pickford. J. S. = James Somerville, professional driller, Newberry.
[b] Altitudes are barometric.
[c] Drawn off 3.5 feet below surface and piped to gristmill on lower ground to cool a gasoline engine. It is 22 feet from the Crawford well, and greatly weakened that well when piped to lower ground.
[d] Can be easily lowered only to 8 feet below surface by heavy pumping.
[e] Flows into open well 12 feet below surface. New pipes were driven in 1900, as the old ones had begun to leak.

Flowing wells of Pickford (T. 43 N., R. 1 W.)—Continued.

Owner.	Location.	Driller.	When made.	Altitude.	Depth.	Diameter.	Flow per minute.	Head.	Temperature.	Section.			Remarks.
										Red clay.	Slush.	Gravel.	
				Feet.	*Feet.*	*Inches.*	*Galls.*	*Feet.*	*°F.*	*Feet.*	*Feet.*	*Feet.*	
Dr. Webster	Pickford	J. S.	1899	630	128	3	....	0	....	....	....	....	Barely flowed; pump attached.
O. S. Roe	do	(?)	1899	622	68	2	....	+6	45.8	....	....	....	Piped to barrel.[a]
A. Taylor	do	(?)	(?)	630	78	....	....	0	....	....	....	....	Barely flows.
W. P. McDonald	Sec. 7	J. D.	1903	635	151	2	....	0	....	100	49	2	Do.
W. Bacon	Sec. 6	J. D.	1903	615	86	2	Weak.	+2	....	74	0	12	
J. Clagg	Sec. 6	J. D.	1904	620	120	2	....	0	....	110	8	2	Piped to lower ground.
T. Morrison	Sec. 12	J. D.	1902	635	98	2	.25	+4	....	52	46	....	
J. Taylor	Sec. 13	J. D.	1905	635	114	2	6.0	+8	45.4	110	0	4	(b)
Wm. Wise	Sec. 14	J. D.	1905	650	112	2	.2	....	....	110	0	2	(c)

[a] Piped to barrel 7 feet below the well mouth; flows three-fourths-inch stream. Water is from sand.
[b] Flows over top of pipe 8 feet above surface. Present discharge is through a three-fourths-inch hole in side of pipe 4 feet above surface. Well is 8 feet above Taylor Creek and stands on the creek bank.
[c] Twenty feet above Munuscong River. An older well near it, 65 feet in depth, has a head 15 feet below the surface.

In a district so flat as that near Pickford it is somewhat difficult to determine by barometer the slight differences in altitude of the wells. If we may trust the barometric readings, there is a slight decrease in the height to which water will rise along a line running southwest and northeast through this district, or in the direction of drainage of the west fork of Munuscong River. As indicated in the table, the flow from the westernmost well (that of W. Wise) appears to rise to an elevation 15 feet greater than is reached by flows from the wells in Pickford, while the wells a mile east of Pickford, in the valley of East Fork, on the farms of William Bacon and J. Clagg, have a head several feet less than that of wells in the village. The high land lying a few miles southwest of Pickford seems likely, therefore, to be the main catchment area for this district. The drift is loose textured in that region, the compact laminated clay penetrated by the flowing wells not being present.

A number of wells with strong hydrostatic pressure have been obtained in the vicinity of Pickford on ground a little higher than that within the flowing-well district, as indicated in the table below. They are probably supplied from the same catchment area.

Wells near Pickford having head nearly at surface.

Owner.	Location.			Driller.[a]	When made.	Altitude.[b]	Depth.	Diameter.	Head.	Section and remarks.
	T.	R.	Sec.							
						Ft.	Ft.	In.	Ft.	
R. Smith	43 N.	1 W.	6	J. D.	1905	670	160	2	−30	Clay to gravel at bottom.
E. Cottle	43 N.	1 W.	5	J. D.	......	665	104	3	−30	Largely sand, gravel at bottom 18 feet.
Bronson estate	43 N.	1 W.	5	O.	1905	660	120	....	−27	Mr. Bronson dug a well 27 feet, which caved in and killed him. The well was then driven to 127 feet. Said to be mainly sand.
C. Harrison	43 N.	1 W.	4	J. D.	1905	650	92	2	−14	Clay to gravel at bottom. Cost $23.
F. Bye	43 N.	1 W.	2	J. D.	1905	650	88	2	−10	Clay to gravel at bottom.
J. Dunbar	44 N.	1 W.	30	J. D.	1905	670	82	2	− 7	Do.
W. Best	44 N.	1 E.	31	J. D.	1904	645	91	2	−11	Red clay 73 feet; sand and gravel 18 feet.
Kirkbride	44 N.	1 E.	31	J. D.	1903	640	105	2	− 8	Red clay 95 feet; gravel 10 feet.
J. Henderson	43 N.	1 E.	6	J. D.	1905	630	92	2	− 3	Near east Munuscong River, 8 feet higher than Bacon flowing well and 150 yards distant. Clay to gravel at bottom.
C. Pennington	44 N.	1 E.	33	J. D.	1897	635	92	2	−10	Well entered gravel 8 feet.
I. McDonald	Pickford	......	......	J. D.	1901	635	130	2	− 4	Red clay 115 feet; gravel 15 feet. Supplies engine in planing mill.
J. Hill's store	Sterlingville	..	......	......	......	635	125	3	−10	Mainly bluish gray "putty sand." Dug 27 feet; driven 3-inch pipe below.

[a] J. D. = Judson Daley, driller, Pickford. O. = owner.
[b] Altitudes are barometric.

RUDYARD-FIBER DISTRICT.

This flowing-well district is located in the drainage basin of Pine River and the extreme headwaters of the west branch of Munuscong River. It occupies about 60 square miles in Tps. 43, 44, and 45 N., Rs. 2, 3, and 4 W. The Soo Line Railroad traverses it from a point 2 miles northeast of Rudyard westward to a point 2 miles west of Fiber. At the time of the investigation, in the autumn of 1905, there were 66 flowing wells. They are obtained on the general level of the plain, and not, as in the Pickford district, confined to the stream borders. The general elevation of the plain is about 690 feet, or higher than the head of any of the wells in the Pickford district.

The wells show greater head in the northern and western parts of the district than in the southern and eastern parts, thus indicating that the catchment area is on the north and west. There is a range of high limestone hills south of the eastern portion of the area which apparently serves as the catchment area for the Pickford district but not for the Rudyard-Fiber district, there being a decided falling off in head in passing southward toward this limestone ridge in the latter district. There are sandy tracts on the northern and western borders of this district, while an elevated limestone tract lies southwest of it. Both the sand and the limestone are readily absorbent, and likely to be sources of supply for the flowing-well district.

In the flowing-well district there is a heavy coating of red laminated clay nearly free from pebbles, which, like that in the Pickford district, appears to have been deposited in the Glacial Lake Algonquin. This clay is underlain by a sandy slush, which in turn rests upon gravel. Wells are usually driven through the slush, but if screens are used flows of considerable strength may be obtained in it. Without the use of screens the wells soon become clogged.

The water contains a small amount of iron and is moderately hard, though in most cases suitable for boiler use. In a few cases it is sulphurous.

It will be observed by reference to the table that the wells differ greatly in rate of flow. This difference is in part attributable to the texture of the water-bearing bed, the slower flow being obtained in sand and the more rapid flow in gravel.

The temperature is about 45° F. in wells that are not greatly affected by surface influences. In one case a well flows so slowly that the stream freezes in the coldest weather, and rises about 10° above its normal temperature in the hottest; but in wells of rapid flow there appears to be only a fraction of a degree variation in temperature in the course of the year.

Flowing wells in Rudyard-Fiber district.

Owner.	Location.			Driller. (a)	When made.	Altitude.[b]	Depth.	Diameter.	Flow per minute.	Head.	Temperature.	Remarks.
	T. N.	R. W.	Sec.			Ft.	Ft.	In.	Galls.	Ft.	° F.	
Fountain House....	Rudyard..........			J. D.	1903	682	278	2	0.2	+22	47.5	Red clay 204 feet, black clay 20 feet, gray quicksand 53 feet, gravel 1 foot.
J Anderson........	.....do............			J S.	1904	682	285	3	.2	+22	52	Red clay 240 feet, dark sandy slush 40 feet, gravel 5 feet. Distance from Fountain House well about 200 feet.
H Bonner..........	.....do............			G. L	1904	685	268	2	.08	....	50.7	Head not determined.
H Cottle...........	44	2	5	H. C	1901	697	125	45	40	+12	45.8	Soft water with no iron stain. Well estimated to flow more than a barrel a minute. Red clay with some pebbles 90 feet, blue sand 30 feet, gravel 5 feet.
Do.............	44	2	5	H. C.	....	695	233	....	....	+12	....	The deeper borings were failures, as no gravel bed was found, and rate of flow from sand was very slow. Distance from 125-foot well 500 to 600 feet.
Do.............	44	2	5	H. C.	....	695	233	....	....	+12	....	
Do.............	44	2	5	H. C.	1895	700	84	....	....	....	....	Well was one-fourth mile east of the others and flowed a strong stream. Pipe was pulled when the 125-foot well was obtained, that being nearer the residence.
B Weiring..........	44	2	6	G. L.	1904	695	190	2	.25	(?)	55	Red clay 140 feet. Sand to cemented crust at bottom. Flows from pipe 5 feet above ground.
J. Kamper..........	45	2	32	J K.	....	700	100	1	....	+ 1	55 32	Flows about 1 gallon an hour. Penetrated hard clay 45 feet, soft clay 35 feet, gray quicksand 20 feet. Freezes in coldest weather.
Do.............	45	2	32	J. K.	....	700	90	....	....	+ 1	55 32	Freezes in coldest weather. Section and rate of flow similar to preceding.
G Kamper.........	45	2	32	G. K.	1905	700	90	2	....	+ 1	50	Red clay pebbly in lower part, gravel at bottom. Weak well.
L. A. Halbert.......	45	2	31	J. K.	1905	700	118	2	.25	+ 8	50	Red clay 85 feet, sand 25 feet, gravel 8 feet. Slight iron stain.

[a] Drillers' initials:
G. L.= George Lawler, professional driller, Rudyard.
J. D.= Judson Daley, professional driller, Pickford.
J. S.= James Somerville, professional driller, Newberry.
G. H.= George Huntley, farmer, Rudyard.
J. K.= John Kamper, farmer, Rudyard.
G. K.= George Kamper, farmer, Rudyard.
G. D.= Garrett Dolman, farmer, Rudyard.
H. C.= Henry Cottle, farmer, Rudyard.
D. B.= D. Boucher, farmer, Rudyard.

[b] Altitudes of wells near Soo Line Railroad determined from railroad survey; remainder, barometric.

Flowing wells in Rudyard-Fiber district—Continued.

Owner.	Location. T. N.	Location. R. W.	Location. Sec.	Driller.	When made.	Altitude.	Depth.	Diameter.	Flow per minute.	Head.	Temperature.	Remarks.
						Ft.	*Ft.*	*In.*	*Galls.*	*Ft.*	° F.	
W. Johnson	45	2	33	G. D.	....	695	68	3	5	+ 8	46	Red clay 50 feet, sandy slush to gravel at bottom. Sulphurous water.
G. Dolman	44	2	4	G. D.	1905	700	72	2	.5	+ 2	46	Flow affected by Johnson well. No sulphur taste.[a]
H. H. Wyatt	44	2	5	J. S.	....	700	104	3	.3	+ 4	....	Not visited.
D. Boucher	44	2	17	D. B.	1898	685	220	2	....	+ 4	....	Flows into basin. Red clay 175 feet, blue sandy slush 20 feet, fine sand at bottom. Weak well.
J. Desrocher	44	2	17	G. L.	1905	685	216	2	1	+25	46	Red clay 208 feet, sandy slush 4 feet, blue gravel 4 feet.
P. Royer	44	2	7	G. L.	1905	685	270	....	....	....	....	Head barely at surface.
G. Kelly	44	2	8	J. D.	....	680	113	3	....	+ 4	....	Flow greatly decreased in summer of 1905.
S. Kendrick	44	2	5	J. S.	1896	680	100	3	8	....	45	Discharges 2 feet above surface from 1½-inch pipe.
H. Johnson	44	2	8	G. H.	1896	680	98	3	3	+ (?)	45	Discharges 3½ feet above surface from ¾-inch pipe.
G. Huntley	44	2	5	G. H.	1897	680	96	3	3	(?)	45	Discharges 3 feet above surface through ½-inch hole.[b]
A. Pitsen	44	2	9	G. H.	1898	680	92	5	4	(?)	45	Flows from ¾-inch hole in side of pipe.
T. Micheau	44	2	4	G. H.	1900	680	92	3	5	(?)	44.5	Do.
—— Naeme	44	2	8	J. S.	1898	680	98	3	.5	(?)	....	Hard crust at bottom.
—— Nesse	44	2	9	G. L.	1904	680	104	2	....	0	....	Head barely at surface.
—— Bolman	44	2	4	G. L.	1904	680	82	2	....	+ 2	....	Flows mere trickle. Enters gravel 2 feet.
—— Glastader	44	2	3	(?)	(?)	685	100	3	.1	+ 3	....	Flows scarcely a pint a minute.
Michigan Land Co.	44	2	10	(?)	(?)	680	(?)	(?)	....	+ 5	48	Flows a mere trickle 5 feet above surface.
—— Habella	44	2	9	J. D.	1903	680	108	2	{32 10}	+ 5	....	Flow of a barrel a minute was reduced to 10 gallons by driving pipe to a crust of hardpan under the gravel. Red clay 100 feet, gravel 8 feet.
—— Housin	44	2	3	G. L.	1904	680	151	2	3	+ 5	45	Discharges from ½-inch faucet 4 feet above ground.
Rev. G. A. Smith	44	2	10	J. D.	1903	680	171	2	1.25	(?)	45	Largely through soft sandy slush. Was driven 115 feet in 1½ hours.
—— Gervin	44	2	10	....	....	680	100	3	....	0	....	Barely rises to surface.
A. Wice	44	2	16	....	1899	680	88	3	....	0	44.5	Do.
—— Jacobson	44	2	9	G. H.	1901	680	113	2	....	0	43.5	Do.

—— Germain	44	3	12	G. L.	1905	680	403			00		Fine sand below red clay. Very weak flow.
H. Loughheed	44	3	10	J. S.	1896	685	165	2		+1 / 0	46	Flowed for 2 years.
Mrs. J. Poirier	44	3	11	J. S.	1897	686	167	3		1 / 0	46	Flowed a ½-inch stream at first.
—— Turcot	44	3	11	(?)	1902	678	160	3	.25	+7	45.7	Discharges through ½-inch hole 3 feet above ground.[c]
G. Vigneu	44	3	11	(?)	(?)	688	±160			0		Head barely at surface.
A. Le Gault	44	3	11			688	±160			0		Do.
C. Gowan	44	3	9	J. S.	1901	695	145	3	2 / 1	2.5	45.75	Red clay 16 feet, gravel and clay 10 feet, red clay to gravel at bottom. Flow is decreasing.
J. T. Joyal	Dryburg			J. S.	1904	680	158	3	2.5	+10	46	Red and blue clay 110 feet, gravel 1 foot, clay and sand alternating 47 feet. Gravel at bottom.
E. Baril	do			J. S.	1899	685	153	3	2.5 / 1.25	+5 / +3	46	Lowered 2 feet by Joyal well, 300 yards distant.[d]
J. Elferdink	do			J. S.		690	147	3	.6	+2	45	Not affected by Joyal well, ¼ mile distant.
C. Everett	44	3	17	J. D.	1901	685	104	2	.2	+15	47	Red clay 102 feet, gravel 2 feet.
R. G. Trimble	44	3	17	J. S.	1900	690	130	3	1.5	+13	46	Discharges from pipe 6 feet above ground.
T. Askwith	44	3	17	G. L.	1904	690	138	3	5	+13	45.5	Head tested when well was first made.
J. B. Wilson	44	3	17		1900	690	135	2	2.5	+13	45	Discharge pipe 7 feet above ground.
H. Ferstneau	44	3	16	J. D.	1901	690	116	2	.25	+3		On bank of Bear Creek 25 feet above stream.
T. Holland	44	3	16	J. S.	1901	680	115	3	1	+12	45	Red clay to gravel at bottom.[e]
Armstrong Mill	Fiber			J. S.	1903	697	110?	3	10	+17	45	Discharges 7½ feet above surface. Water suitable for boiler use; very little scale. Red clay 85 feet from sand under cemented crust.
T. Anderson	do			J. S.	1900	697	110	1½	1	+18	44.3	Red clay 100 feet, sand 10 feet. Discharges 8 feet above surface and is piped to dwelling.
Ross & Bros. mill (2 wells).	2 miles west of Fiber.				1898	735	115	1½	10	(?)		Mainly red clay. Pipes now pulled.[f]
—— Savoie	44	3	21		1903	685	113	2	.5	+5	46	Gravel 1 foot at bottom.

[a] If the Johnson well is allowed to flow freely it will lower the head of the Dolman well 7 inches within an hour, but not so rapidly after the first hour. Distance between the wells about one-eighth mile.

[b] A well near this was dug 50 feet and bored 24 feet. It obtained a flow, but the water had a rank odor, coming from a black sand struck at about 40 feet. Odor apparently sulphurous. The well was filled and the present well, which apparently missed the black sand, was drilled. Its section is: Red clay, 74 feet; blue sandy slush, 6 feet; gravel, 20 feet.

[c] This well is in a ravine 100 to 150 yards distant from the Loughheed and Poirier wells and is thought by the owners to have caused the loss of head in those wells. It appears, however, that the Loughheed well began losing head before the Turcot well was sunk.

[d] The Baril well is about 300 yards northeast of the Joyal well and appears to be influenced by the flow in that well. When the Joyal well was opened the Baril well ceased flowing for two days, and then came back to a head 2 feet lower than when first made and to half its original rate of flow.

[e] An old boring about 20 feet distant and on ground 6 feet higher still flows, though the pipe has been pulled.

[f] Two wells only 10 yards apart each flowed a full pipe, 1½-inch stream. Holes 3 inches in diameter were drilled and 1½-inch pipes inserted in them, but since the mill has ceased operation the pipes have been pulled and the water escapes around the holes.

Flowing wells in Rudyard-Fiber district—Continued.

Owner.	Location.			Driller.	When made.	Altitude.	Depth.	Diameter.	Flow per minute.	Head.	Temperature.	Remarks.
	T. N.	R. W.	Sec.									
						Ft.	*Ft.*	*In.*	*Galls.*	*Ft.*	° F.	
R. Cartright	44	3	22	J. S.	1902	685	132	2	....	....	....	Flows a mere trickle.
H. McCraig	44	3	22	(?)	1900	685	(?)	2	.25	+ 5	47	
E. Davidson	44	3	22	J. S.	1898	680	147	3	.75	+1.5	46.5	Red clay 75 feet, sand below.
Do	44	3	27	J .S	1903	680	150	2	1	+ 3	....	Similar to preceding.
—— Dersher	44	3	28?	J. D.	1901	....	114	2	....	+ 2	....	Not visited.
—— Ackridge	43	3	4	....	1904	....	117	2	.25	....	....	Do.
A. Douglass	44	3	35	G. L.	1904	670	188	2	{ 36 { 12.5	....	45	Flow decreasing.[a]
S. N. Peffer	44	3	36	G. L.	1904	670	186	2	2.4	....	46	Red clay 180 feet, sandy slush 6 feet. On bluff 40 feet high. Slight iron stain.
P. Stevenson	44	2	31	G. L.	1904	670	173	2	3	....	46	Red clay to sand at bottom.
S. McDonald	44	2	31	G. L.	1904	670	208	2	.5	+ 2	46.5	

[a] This well when first drilled, in August, 1904, was one of the strongest flows in this district, the discharge being about 36 gallons a minute from a 2-inch pipe. It began to decrease perceptibly in May, 1905, and on August 22, 1905, discharged only 12½ gallons a minute.

About 2 miles northeast of Rudyard there is a tract of land whose altitude is 715 to 730 feet, or about 30 to 45 feet above Rudyard station. The red clay is comparatively thin on this prominent tract, and wells are obtained in gravelly sand at depths of 28 to 42 feet. In three of the wells on ground about 715 feet above tide the water stands only 6 feet below the surface. One of these, at the residence of J. C. Sass, will stand pumping 2 barrels in seven minutes without lowering, though it has only a 3-inch pipe. The source of supply for these wells is probably to the north in the higher land, which is loose textured and free from the capping of red clay.

STRONGVILLE.

Several deep wells near Strongville, 2 to 3 miles south of the eastern part of the Rudyard-Fiber flowing-well district, on ground 10 to 20 feet lower than the flowing wells, have a water level several feet below the surface, as indicated in the table below. As already stated, the passage of underground water appears to be from north to south, and this naturally results in the decrease of head here displayed.

Wells near Strongville (T. 44 N., R. 2 W.) with strong hydrostatic pressure.

Owner.	Location.	Altitude.[a]	Depth.	Head.	Remarks.
		Feet.	*Feet.*	*Feet.*	
L. R. Adamson	Sec. 21	670	147	−12	Red clay 130 feet, black sandy slush 15 feet, gravel 2 feet. Strong well with 3-inch pipe in lower part, but dug 4 feet square to depth of 37 feet.
George Potts	Sec. 26	670	120	−20	
M. Knauf	Sec. 28	670	144	−16	Similar to Adamson well, but not so strong.
D. Perry	Sec. 22	670	67	−20	Weak well.

[a] Altitudes are barometric.

EMERSON.

There are nine flowing wells at Emerson, on the shore of Whitefish Bay, all on the property of the Cheesbrough Lumber Company. They range in depth from 116 to 123 feet. In each well a 5-inch hole was made and cleaned out, then a 1¼-inch pipe inserted. The wells passed through 17 feet of sand and then 90 to 95 feet of blue clay to sand at bottom. The clay is said to be laminated and pebbleless and is apparently a lacustral rather than a glacial deposit. The rate of flow ranges from less than a pint a minute in the weakest to 1½ gallons a minute in the strongest wells. The escape pipes are from five-sixteenths to three-eighths inch in diameter, and the water will rise to a height of 5 or 6 feet above the level of Lake Superior. It carries a small amount of iron, but appears to have very little lime, as is natural, in view of the fact that this well district is north of the limestone formations. The temperature ranges from 44° to 49° F in the different wells. These wells are distributed over a space of about half a section and the area of flows might perhaps be extended 2 or 3 miles along the shore of the bay.

TAHQUAMENON DISTRICT.

Occurrence.—The Tahquamenon district embraces several groups of flowing wells distributed along the southern border of a large swamp traversed by the east and west branches of Tahquamenon River in western Chippewa and southern Luce counties. Flows have been obtained at Strong and Eckerman, and near Soo Junction, Newberry, and Dollarville, and can probably be obtained along the swamp between these stations. This district, like the Pickford and Rudyard-Fiber districts, lies in the lowland underlain by the "Lorraine" (Hudson) and "Utica" formations, in a belt of thick drift. There is no heavy and continuous deposit of laminated clay here as in the other two districts mentioned. Instead the wells often penetrate a large amount of fine sand and, in some

cases, scarcely any clay. Located, as this district is, in a trough-like lowland, it seems to afford favorable conditions for receiving water both from the south and north. On the south is a morainic belt with pervious drift, largely of sandy gravel, which will readily absorb water to supply the low tract where the wells are found. On the north also is a moraine of loose-textured drift, under which the rocks dip southward beneath this swamp. The altitude of the wells ranges from about 725 feet at Dollarville and points farther east, near Tahquamenon River, to nearly 850 feet at Strong. The wells of high altitude are along the east branch of Tahquamenon River, a stream that descends rapidly westward, but the wells of low altitude are along the west branch, a sluggish stream flowing eastward. It is probable that the underground drainage of the east fork leads westward, conforming to the slope of the surface, and this may be a leading cause for the westward decline in head. The head declines northward toward the west fork, from the southern moraine a distance of from 1 to 3 miles, but it can scarcely be expected to continue farther north, in view of the northward rise of both the drift surface and the underlying rock formations. The water is of fair quality for boiler use, though moderately hard. It contains a small amount of iron.

Strong.—At Strong, in western Chippewa County, are two flowing wells, one at Turner's mill and one at the boarding house, both driven in 1899 by James Somerville. The altitude of the mill well is about 840 feet and that of the boarding-house well 845 feet. The mill well was driven to rock at 220 feet, but the pipe was pulled back to 185 feet because of a flow of water from the sand bed at that depth. The well passed through clay to this water-bearing sand. The flow is only a quart a minute from a 2-inch pipe and the temperature is 45.8° F.

The boarding-house well is 203 feet in depth and discharges about 2 gallons a minute from a 2-inch pipe. Part of the water is piped to the mill. It has a temperature of 46° F. After passing through 7 feet of surface sand, the well penetrated 168 feet of clay that changed in color from red to gray toward the bottom. Beneath this clay was 10 feet of gravelly hardpan, then 16 feet of quicksand, followed by a hard crust 2 feet thick, under which a flow of water was struck.

Eckerman.—At Eckerman three shallow flowing wells have been obtained at about the level of the railroad station, or 800 feet above tide. They are at the base of the moraine that passes Eckerman on the south and are probably supplied from it. The well at George Johnson's hotel, made in 1896, is 47 feet in depth, 3 inches in diameter, and discharges 6 quarts a minute through a half-inch pipe about 5 feet above the surface, or 808 feet above tide. The flow at first was 2 gallons a minute. The temperature of the water is 44.2° F. The well penetrated reddish till for 40 feet and sand for 7 feet.

A flowing well at Lake's livery stable is 35 feet deep and flows 2 quarts a minute, the water having a temperature of 44.8° F.

At the dwelling now used as the post-office, just east of the railroad depot, is a 35-foot well, which penetrated 15 feet of sand before entering clay, and terminated at the bottom of the clay bed. Although the water overflowed, a pump is now used, and the temperature by pumping is 44.8° F.

Soo Junction.—A flowing well 172 feet deep and 3 inches in diameter was made in 1893 by James Somerville on the White and France property north of Soo Junction, on the north side of Tahquamenon River at an altitude of about 720 feet above tide. It was largely through a "putty clay," but there was a thin bed of gravel resting on the rock. The head was 8 feet above the surface when drilled. This well was not visited by the writer and its present condition was not ascertained.

Newberry.—There have been several shallow flowing wells at Newberry, on the low ground in the northwestern part of the village. These are now drained by deeper wells at the furnace and chemical works. The shallow wells pass through a thin bed of clay 6 to 18 feet, beneath which is a fine sand that changes to coarser at a depth of about 30 feet. The flows are of moderate strength, one being as high as 3 gallons a minute. The altitudes are 755 to 760 feet.

The well at the furnace, at an altitude of 760 feet, is 80 feet deep, and flows if pumping is discontinued for a few hours.

At the chemical works, 100 yards north of the furnace, are ten wells with depths ranging from 80 to 108 feet, all 6 inches in diameter. The first well was put down 128 feet and entered a hard material, possibly bed rock, for a few inches. The pipe was then pulled back to about 100 feet. All these wells will flow after a brief intermission from pumping. The water is sufficiently hard to form a coating of lime on the stills. It is struck at about 20 feet from the surface in fine sand under a clay bed. The sand increases in coarseness below, and for this reason the wells are extended to the depths named. The amount of water obtained seems unlimited. No temperature observations were taken, since the water is carried some distance through surface pipes before discharging.

At Harris's celery farm, in the northeastern part of Newberry, is a driven well 60 feet in depth, which formerly flowed, but now has a pump attached, the water scarcely rising to the surface. Near this well, at a railroad section house, is a well 765 feet above tide, which has flowed, but is now pumped. It was sunk in 1889 to a depth of 54 feet. The temperature of the water is 45° F.

On the Ryberg farm, about half a mile east of the wells just mentioned and at the same altitude, is a well 142 feet deep which is still flowing 3½ feet above the surface, discharging 3 pints a minute. The temperature is 45° F.

The public supply of the village of Newberry is from three 6-inch wells 110 feet in depth, which have a head of about 10 feet, the ground being about 15 feet above the level of the railroad station, or 780 feet above tide. The wells are through sand to a depth of 90 feet, where a bed of gravel is struck which furnishes an unlimited supply of water. It is of moderate hardness and carries but little iron.

Dollarville.—The Danaher Lumber Company has three flowing wells at the village of Dollarville, 2 miles west of Newberry, one of which has a flow of 10 gallons a minute; the other two are much weaker. There is a fourth well with water near the surface, but it has a pump attached. The strong well is located about 200 yards east of the railroad station at an altitude of about 725 feet above tide. It is thought to be 95 feet in depth and is 3 inches in diameter with a 1-inch discharge pipe. The water supplies several families and is piped to a livery barn. It has a slight iron taste and is moderately hard. The temperature is 45° F. A well about 300 yards farther east flows 3 quarts a minute and has a temperature of 46° F. The water carries considerable iron and stains boards and other objects over which it flows. The well is thought to be about 130 feet deep and appears to have struck rock at the bottom. Another well, now plugged, also appears to have reached rock at 120 feet; its water tastes of sulphur, which seems to indicate that it may be supplied in part from the rock. All the wells penetrate a bed of clay above the water bed.

South of Dollarville.—In a recess of the moraine 2 or 3 miles south of Dollarville are flowing wells at an altitude 15 to 20 feet higher than those in the village, or about 740 feet above tide. A prominent ridge stands between these wells and the village of Dollarville. The first well of this group was dug in 1889 on the John Carlson estate in the west part of sec. 9, T. 45 N., R. 10 W. It was through red clay nearly to the bottom, ending in sandy slush at a depth of 102 feet. The water barely rises to the top of the well, so a pump is now attached. About one-fourth mile east of this well and on slightly lower ground John Hunter has a strong flowing well 103 feet deep, which penetrated only 40 feet of red clay and was then in sandy slush to a gravel bed at the bottom. The water in this well rises at least 11 feet above the surface, or to fully 750 feet above tide. It once discharged a full stream from an inch pipe at an estimated rate of 20 gallons a minute, but now burst up around the pipe, thus lessening the discharge through the latter. The water is hard and carries a little iron. The temperature is 45 F°. There are several strong boiling springs near this well. About one-half mile southeast of the Hunter well, in the southwestern part of section 10, is a flowing well 103 feet deep on the farm of A. Pentland. It discharges 2 quarts a minute, with a temperature of 45.5° F. It was largely through red clay to sand

at 90 feet. In the northwestern part of section 11, on the farm of John Peterson, is a flowing well 53 feet deep which yields a gallon a minute, the temperature being 45° F. This well was mainly through red clay to sandy slush at bottom, in which the pipe is suspended. If unsupported the pipe would sink several feet into the slush. About 300 yards east of the Peterson well, in the southwestern part of section 2, on the farm of John Swanson, is a flowing well 84 feet in depth. The altitude appears to be about 10 feet higher than that of the other flowing wells of this group, or 750 feet, and the head is only 2 feet above the surface, so a siphon is used to carry the water into a tub. This well passed through sand for its entire depth. A 3-inch hole was made, but the pipe is only 1¼ inches. The flow is 3 quarts a minute and the temperature 45° F. Near this well, along a small stream, are boiling springs covering an area several yards square, which probably have a similar source with the wells. Other strong boiling springs occur one-half mile south on the borders of a lake.

The flowing wells near Dollarville are the westernmost yet developed, but it is probable that flows can be obtained along the swamp westward across the divide between the Tahquamenon and Manistique drainage basins, and possibly throughout the southern part of the great swamp drained by Manistique River. The latter swamp is uninhabited and is so flooded with surface water that there is no occasion to test for flowing wells. The village of Germfask, which stands near the southeastern edge of the swamp, may, however, find it worth while to test for such wells.

ISOLATED WELLS IN BASINS.

It is probable that flowing wells may be obtained in small basins on the borders of lakes or in swamps.

Shelldrake.—One such well is reported to have been obtained in a swamp west of Shelldrake, in Chippewa County, at a lumber camp in sec. 28, T. 49 N., R. 7 W. It is only 16 feet deep and apparently passed through nothing but swamp muck to the sand bed that yields the flow. The swamp is surrounded by sand ridges rising 20 to 30 feet above it, and they probably serve as a catchment area and furnish the head.

Helmer.—Another isolated flowing well is at Helmer post-office at the east end of Manistique Lake, in the southwestern part of Luce County. The depth is 70 feet, and water is from gravel below clay. The head is at least 8 feet, or about 15 feet above Manistique Lake and 715 feet above tide. The water is piped into the hotel owned by Mr. Helmer. The natural rate of flow could not be determined, because a stone had become lodged at the bottom of the pipe, greatly obstructing the discharge. The temperature is 46° F. This lake is in a basin in a morainic belt, and it is probable that flowing wells can be obtained at other points on the shore.

ONTONAGON COUNTY.[a]

A flowing well 355 feet in depth was made by Mr. Geismar in 1893 near Ewen, Ontonagon County, in sec. 21, T. 48 N., R. 39 W. It is at about the same altitude as Ewen station—1,134 feet. It penetrated a pebbleless, gritless red clay for 125 feet, under which was found a gravel bed 13 feet thick, yielding a weak flow. A sandy clay slush was then struck, which extended to 354 feet, where gravel with a strong flow of water was found. The well discharged a full 1-inch stream 16 feet above the surface. The well is remarkable because of great variations in the temperature of the water. In the winter months this is about 44° F., but in the spring, about the time of the snow melting, a lowering of temperature is noted, which continues till about June 1, when it reaches 38° F. This low temperature continues well into the summer before a rise begins. Mr. Geismar refers the low temperature to the access of snow water to the bed of gravel from which the well flows.

There are three flowing wells at Ewen, belonging to the village, with depths of 208 to 224 feet. They penetrated red clay to the water-bearing gravel at the bottom. Beneath the gravel is a reddish rock, thought by the drillers to be granite. The wells flow with considerable strength.

[a] Data furnished by Superintendent Leo Geismar, of the State experimental farm at Chatham, Mich.

FLOWS FROM ROCK.

NORTHERN BORDER OF LAKE MICHIGAN.

Occurrence.—Flowing wells have been obtained at several points near the Lake Michigan shore from St. Ignace westward to Manistique, and at various depths. So far as ascertained they are all from the rock, and there appear to be two or more horizons from which flows are obtainable. Part of the data concerning these flows are from the annual reports of the State geologist for 1901 and 1903, and the only interpretations as to geologic horizons are those presented by him. As already stated, the present writer had no opportunity to examine samples of well drillings nor to get accurate data on the formations penetrated. The flowing wells now obtained range in altitude from near lake level up to about 100 feet above, or from 600 feet or less up to about 680 feet above tide. It is not certain, however, that wells may generally be expected to flow to levels 100 feet above the lake. More likely the upper limit will be found to be generally within 50 feet above lake level. This opinion is based on the fact that some of the wells near lake level, such as those at Manistique, have not sufficient pressure to rise 50 feet above the lake.

St. Ignace.—Two deep flowing wells have been made in the vicinity of St. Ignace at an altitude of 20 feet above the lake, or 600 feet above tide, the first in 1887 and the second in 1901. In the first the Monroe beds extend down to about 500 feet and yield a small amout of bitter salt water. The Niagara and "Clinton" limestones extend 400 feet farther down, the Medina (?) sandstone being struck at 900 feet and penetrated 19 feet. In the second well, located about 2 miles north of the old one, in sec. 31, T. 41 N., R. 3 W., the Niagara is reached at 400 feet and supplies a flow of water from a depth of 575 to 681 feet and more at 1,040 feet. This well was stopped at 1,155 feet. The temperature of the flow was found to be 51° F., or about 6° above the temperature of shallow flowing wells, though 2° less than in wells of similar depth at Cheboygan and Alpena.

Engadine.—A strong flowing well was made in 1905 on the farm of Peter Praten north of Engadine, in sec. 4, T. 43 N., R. 10 W., at the altitude of Engadine station (674 feet). It is only 60 feet deep, but enters limestone for some distance. At the village of Engadine are two deeper wells, one of which, 206 feet deep, had a weak flow, and the other, 146 feet deep, had water nearly level with the surface. The deeper of these two was made by the lumber company in July, 1905, and flowed for a month or more, but became clogged with sand. The other, located at the mill, has never flowed. The sand is thought to work down into crevices in the limestone outside the pipe in the deeper well, thus choking it.

Deuels Lake.—The Simmons Lumber Company has an intermittent flowing well on the shore of Deuels Lake, about 10 miles southwest of Engadine, in sec. 23, T. 42 N., R. 11 W. The well is 108 feet in depth and is in limestone from a depth near the surface. The water rises 3 feet above the surface in the spring and early summer, but in the fall it drops below the surface, apparently on account of drought. The altitude is estimated to be scarcely 50 feet above Lake Michigan, and the well is less than 2 miles from that lake. It is probable that similar flows can be obtained along the shore of Deuels Lake at other points. Possibly a deeper well might obtain water with sufficient head to flow through the dry season.

Hunt Spur.—A well was made about 1890 by the Michigan Cedar Company at Hunt Spur, on the Soo Line Railroad, near the western border of Mackinac County, which discharged a stream with sufficient force to throw a jet 20 feet in the air. A hose was attached, and the flow was used in cleaning off logs. No data were obtained concerning the depth, but it is thought not to exceed 200 feet. The altitude of the well mouth is 684 feet, and the well is in limestone from a depth near the surface. Another well at a barn of the same company has a weaker flow.

Manistique.—There are several flowing wells in Manistique with depths between 200 and 300 feet and one (at the Hiawatha Hotel) with a depth of 800 feet. The shallower wells have a head in some cases about 16 feet above the surface, or 630 feet above tide, while the deep well at the Hiawatha Hotel is said to have a head 30 or 40 feet above the

surface, or about 650 feet above tide. The State geologist in the report for 1903 interprets the horizon of the deep flow to be Trenton, and of all the others to be Niagara. The temperature of the shallower wells is 45° to 46° F., as noted by both the State geologist and the writer.

Several of the flowing wells are furnished with fire hydrants and are drawn on in case of fire, the yield by pumping being sufficient to supply all the water needed.[a]

SHORE OF BIG BAY DE NOC.

Garden Peninsula.—On the western side of Garden Peninsula, at Vans Harbor and Garden village, strong flowing wells have been obtained, concerning which the following data were furnished by the driller, George W. Gray, of Cooks Mill, Mich.:

Flowing wells on Garden Peninsula.

Owner.	When made.	Altitude.	Depth.	Diameter.	Flow per minute.	Head.	Remarks.
		Feet.	*Feet.*	*Inches.*	*Galls.*	*Feet.*	
L. Van Winkle	1905	590	233	5	60	+18	The only flow at Vans Harbor. Cased 40 feet; limestone at 18 feet under bowldery clay.
W. Stillwagon	1902	592	175	....	40	+16	Deepened an old well 82 feet. First flow at 107 feet; stronger flow at 173 feet. Used for fish pond and house.
Bondreau & Disco	1903	588	199	5	30	+18	Two water beds, as in preceding well. Limestone under bowldery clay at 20 feet. Cased 38 feet and at a leakage at 60 feet.
Garden village:							
No. 1	1902	593	195	....	25	+ 6	Limestone under red clay and sand at 14 feet. Cased 52 feet. Flow weaker than 25 gallons July to October and January to April.
No. 2	1903	595	220	....	....	....	Now plugged because it drained well No. 1, but water comes up around pipe. Main flow at 193 feet.
No. 3	1905	588	104	5	8	....	Drift, very bowldery at 12 feet.

The decrease in the flow of the village well No. 1 seems referable to drought in the late summer and the frozen condition of the ground in the winter. The second village well, although on slightly higher ground, apparently has an advantage over the first by drawing water from a lower depth.

Conditions seem very favorable for obtaining flowing wells along the Lake Michigan slope of the Garden Peninsula, but no instances of the occurrence of such wells came to the writer's notice. The shore rises gradually back from the lake and the flowing-well belt should extend a mile or more inland.

Nahma.—At Nahma, on the western side of Big Bay de Noc, opposite Garden, are two flowing wells made by the Big Bay de Noc Lumber Company. One sunk in 1883 is 133 feet deep, 2 inches in diameter, and flows scarcely a gallon a minute. It ends in limestone. Another sunk in 1895 is 80 feet deep, 4 inches in diameter, and will fill a barrel in about five minutes. It does not enter rock.

Probably flowing wells are obtainable at moderate depths both along the shore of the bay and up the Sturgeon River Valley, but no others have come to the writer's notice.

[a] The city is now (1905) building a waterworks plant which will obtain water from Indian Lake, which lies about 3 miles to the northwest.

BORDER OF LITTLE BAY DE NOC.

Rapid River.—In the village of Rapid River, at the head of Little Bay de Noc, several flowing wells are in operation and two flows have been obtained in test wells for oil several miles north of the village, which show a possible extension of the district in that direction. It is probable that flowing wells may be obtained along the entire western side of the bay on ground below the 600-foot contour, and in places at higher altitudes, as in the Hendricks boring noted below.

Flowing wells at Rapid River.

Owner.	Location.	When made.	Altitude.	Depth.	Flow per minute.	Temperature.
			Feet.	*Feet.*	*Galls.*	*° F.*
A. Conner	East of Main street	1895	588	270	0.75	46.8
H. W. Coles	do	1897	586	258	2.00	45.0
Village No. 1	Main street	1897	588	273	4.00	45.5
Village No. 2	West of Main street	1898	590	275	1.5	45.5
Dr. A. Laing	do	1903	590	273	2.0	45.5
A. Schaible	do	1904	588	273	6.0	45.2
A. Bodah	North part of town	1899	590	275		
Mrs. J. Fish	Half mile west	1897	593	273		
School well	Masonville	1905	590			

The wells at Masonville, which are located a mile southwest of Rapid River, and the Fish and Bodah wells in Rapid River, were not visited. The head was not determined in any of the wells, though it is known to exceed 8 feet, some of the wells having been carried to that height without reaching the full limit.

The two oil-well borings, 7 miles north of Rapid River, in sec. 34, T. 42 N., R. 21 W., were each drilled to a depth of 800 feet or more. Samples inspected by the State geologist form the basis for the following interpretation of the strata penetrated:

Hypothetical log of Rapid River oil well.

	Thickness.	Total.
	Feet.	*Feet.*
Swamp, peat, and muck	6	6
Marl	10	16
Trenton limestone with geodes	264	280
St. Peter (?) / Undifferentiated "Calciferous" } with strong flow of water, temperature 47.3° F	350	630
Potsdam sandstone (white)	80	710
Potsdam sandstone (red)	50	760
Feldspathic sandstone (Potsdam)	10	770
Micaceous red sandstone (Potsdam)	30	800
Decomposed chloritic schist, like Archean rocks, at bottom.		

Gladstone.—At the furnace in the northern part of Gladstone there are several flowing wells which range in depth from 230 to 700 feet and have diameters of 4 and 6 inches. They are about 5 feet above lake level, and one has a head 27 feet above the lake, or 607 feet above tide. There are two horizons from which flows are obtained, one being at about 230 feet and the other about 700 feet, with small quantities of water at intervening levels. The lowest water horizon is reported to be the strongest and the water is thought to be softer than in wells of shallower depth. This, however, was not verified by chemical analyses. The earliest well was made about 1899 and others have been sunk from time to time as needed.

Temperatures reported by Lane are found to range from 44.9° to 49.3° in the different wells, the highest being in a well 500 feet deep.

At a boarding house kept by Mrs. Martin adjacent to the furnace is a well 230 feet deep and 4 inches in diameter, made in 1902, which yields a moderate flow.

At the roundhouse in the western part of Gladstone a well made by the Minneapolis, St. Paul and Sault Ste. Marie Railway in 1903 reached a depth of about 700 feet and obtained a strong supply of water at 690 feet, which stands a test by pumping of 150 gallons a minute and has a hardness of 5.86° on Clark's scale. The water rises to 12 feet below the surface or about 600 feet above tide, the railroad station near by being 612 feet. The following record appears in the report of the State geologist for 1903:

Log of railroad well at Gladstone.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	51	51
Clay and hardpan	10.5	61.5
Sand and gravel	15	76.5
Clay and limestone bowlders	14.5	91
Trenton limestone	234	325
Sandstone and limestone (St. Peter?)	89	414
Undifferentiated "Calciferous" limestone	228	642
Potsdam sandstone	100	742

Hendricks.—A boring in sec. 8, T. 41 N., R. 24 W., obtained a weak flow from a reddish sandstone which was struck at 350 feet and penetrated for 146 feet. It is a 4-inch well and was made in the winter of 1901-2, at a cost of about $1,000.[a]

WEST SHORE OF GREEN BAY.

Several flowing wells have been sunk in the cities of Escanaba and Menominee, Mich., as well as at cities and villages on the borders of Green Bay in Wisconsin. The flows are partly from the St. Peter sandstone and partly from the Potsdam. Possibly the sandy beds of the "Calciferous" also yield flows, and they may be obtainable from the Trenton limestone at certain points. The few data here presented are from the annual report of the State geologist for 1903:

Log of Wagner well near Escanaba.

	Thickness.	Total.
	Feet.	*Feet.*
Drift, gravel, and clay	9	9
Lorraine (Hudson) shale	192	201
Utica bituminous shale	50	251
Trenton limestone, with geodes or quartz inclusions, at 406 and 457 feet and shale at 485 489 and 518-522 feet	271	522
St. Peter sandstone (in part)	38	560
St. Peter shale	2	562
Undifferentiated "Calciferous" limestone, etc	78	640

[a] Reported by J. M. White, Wells, Mich.

In a recent well near by, a broken formation, perhaps the conglomerate of the Archean quartzite, was struck at 860 to 900 feet; above it was a good body of sandstone.

A flowing well at Flatrock near Escanaba is reported to be 800 to 900 feet deep.

At Menominee S. M. Stephenson has a flowing well in town and another on his farm 3 miles west. The latter is 720 feet deep on ground 30 feet above Lake Michigan and has a head of only 1 foot. Water was found at various levels, but the main supply is at 620 feet. The water of the town well has a temperature of 55.5° F., but no data as to depth of the water bed are reported. A well near the Stephenson Hotel in Menominee is thought to be in Potsdam sandstone, but no definite data are given as to depth, the statement being 500 to 1,000 feet.

There are a number of other flowing wells in Menominee, Marinette, and Escanaba, but the writer is not in possession of data concerning them.

LAKE SUPERIOR SHORE.

Grand Marais.—A deep boring was made at Grand Marais a few years ago, with the expectation of obtaining a flowing well. It is on ground about 30 feet above Lake Superior. It penetrated 100 feet of drift before entering Potsdam sandstone, and was carried 1,100 feet into that rock. The water, though abundant and of good quality, will not overflow, and in consequence no use is made of it. The dip of the rock formations being southward from the shore of Lake Superior, the underground flowage is probably in that direction, or away from the lake shore. This being the case, the further testing of this shore for flowing wells can not be encouraged.

NONFLOWING WELLS.

In the districts where flowing wells can not be obtained a number of records were collected which throw light on the distance to water, and in some cases on the head. In general it may be stated that an exceptionally good water is obtainable, at moderate depths, throughout the part of the northern peninsula underlain by Cambrian and Silurian rock formations. It need scarcely be stated that it is decidedly softer in the sandstone districts bordering Lake Superior than in the limestone districts bordering Lakes Michigan and Huron, a feature which also characterizes the lakes. The water table, except in prominent glacial and limestone ridges and elevated gravel and sand plains, is near enough to the surface to be easily reached by dug wells, a common depth being 20 to 30 feet. Probably 80 per cent of the farm wells are less than 30 feet in depth. The records collected are mainly of wells of exceptional depth, no attempt having been made to compile a complete list. In the statements which follow, the well districts are taken up in order from east to west.

CHIPPEWA COUNTY.

Sugar Island.—On Sugar Island wells are 15 to 25 feet deep. On clay plains they penetrate to underlying sand and gravel, while on gravelly ridges they go down about to the level of the bordering plains.

St. Marys River.—Along St. Marys River from Sault Ste. Marie to the mouth of the Munuscong the wells are generally only 15 to 30 feet in depth, corresponding to their altitude above the river. There are, however, places where a solid bed of clay extends some depth below the river level, as indicated in the following table:

Wells along St. Marys River.

Owner.	Location.			Altitude.	Depth.	Head.	Remarks.
	T. N.	R. E.	Sec.				
				Feet.	*Feet.*	*Feet.*	
B. Gilroy	47	1	22	620	60	−18	Sand 12 feet, red clay 45 feet, gravel and sand 3 feet.
Do	47	1	22	615	77	−10	Section same as preceding.
Sam Presion	47	1	22	615	70	−10	Clay to water bed in gravel at bottom.
D. F. Grier	46	1	22	610	70	{ − 2 { −25	Head at first near surface, but now 25 feet below.
J .W. Hinds	46	1	13	590	100	....	No water obtained. Clay to bottom.
John Baylus	46	1	25	600	80	− 4	Sand 9 feet, clay to gravel at bottom.
J. Wright	46	1	26	600	78	− 4	Sand 7 feet, clay 68 feet, gravel 3 feet.

Wells on the high plain above the Nipissing beach, south of Sault Ste. Marie, at altitudes between 670 and 700 feet above tide, are from 35 to 100 feet in depth, and obtain water from gravel or sand under a laminated, nearly pebbleless, clay. The head is generally 30 feet or more below the surface. Temperatures wherever tested were 45° F. or slightly less.

Pickford.—Wells on the gravelly table-land northwest of Pickford are 55 to 75 feet or more in depth when at an altitude of about 775 feet, and the water rises but little in the wells.

Wellsburg.—On the high sandy plain at Wellsburg, at an altitude of 225 feet above Lake Superior, a well was sunk by the railroad company in 1885 to a depth of 280 feet, entirely through sand. The water rises to —45 feet, or about 180 feet above the lake. A well in the ravine south of the station, about 15 feet lower, obtains water at only 25 feet depth. North of Wellsburg on the same plain are wells 100 to 160 feet in depth. A well on the Van Leuven homestead in sec. 25, T. 47 N., R. 4 W., on a morainic ridge overlooking Lake Superior, and at an altitude about 225 feet above lake level, is 140 feet in depth.

Rexford.—At Rexford, on a high sand plain about 325 feet above Lake Superior, a well was obtained at only 45 feet, and a similar well was obtained at the target range, about a mile west of Rexford. South of these high sand plains, in the vicinity of Trout Lake and Alexander, wells are obtained at slight depth, much of the region being swampy.

Shelldrake.—At Shelldrake, on the shore of Lake Superior, a boring was sunk by Colonel Culhane to a depth of 250 feet without reaching rock, although at an altitude of only 5 feet above Lake Superior. It passed through clay with associated thin beds of sand and obtained a weak supply of water with a head of 60 feet. Several wells in Shelldrake are from 75 to 85 feet, there being but little water obtainable at less than 75 feet.

LUCE COUNTY.

Newberry and vicinity.—In the vicinity of Newberry several deep wells have been made on elevated ground, at the State Insane Asylum, and on surrounding farms. One well at the asylum, 457 feet deep, struck rock (limestone) at 320 feet, and entered shale in the lower 70 feet. Water is from near the top of the limestone, and the well will yield by pumping 200 gallons a minute. It has a diameter of 7½ inches. The head is —104 feet, and the altitude of the well mouth about 865 feet. Another asylum well is 245 feet, and there are four wells 186 feet in depth. All these wells struck the first water bed at a depth

of about 100 feet, and there is little if any rise of water, that depth being apparently the level of the ground-water table. Other wells have been made at wood camps on the asylum property, 1 to 2 miles south and east of the buildings, one well being 100 feet and another 170 feet deep. The deeper well penetrated sand 100 feet and below this a blue hardpan 65 feet, obtaining water in sand under the hardpan. The altitude of these wells is about the same as that of those at the institution. At a schoolhouse near the asylum the well has a depth of 138 feet. A partial analysis of water from a well adjacent to the asylum grounds, made in 1893 by Doctor Nicholson of Newberry, showed the presence of only 65 parts per million of calcium and magnesium carbonates, and but a trace of iron, while chlorides seemed to be entirely absent. The depth of this well is 128 feet and the head —110 feet.

About 2 miles west of the asylum, on a prominent knoll of similar altitude, are three deep wells. One at a schoolhouse, in the western part of section 9, is 192 feet deep and has a head of —135 feet. It was largely through sand. Across the road, in section 10, at the residence of John Templeton, is a well 196 feet deep, with a similar head. About a mile northeast of these wells A. Carlson made a well 150 feet in depth, with a head of —130 feet. The altitude of these three wells is about 850 feet. Another well on lower ground (760 feet above tide), in the southeastern part of section 4, has a depth of 106 feet and a head of —26 feet. There were nearly 20 feet of clay near the top, but the remainder was through sand.

At a limestone quarry 12 miles southeast of Newberry (sec. 6, T. 44 N., R. 8 W.) are two wells 100 feet in depth, with a head 80 feet below the surface. The altitude of the wells is about 900 feet. An analysis of the boiler scale, made by the Dearborn Drug and Chemical Company, Chicago, gave the following proportion of mineral constituents:

Analysis of boiler scale from quarry well water.

	Per cent.
Silica	3.20
Oxides of iron and alumina	1.16
Calcium carbonate	80.08
Magnesium carbonate	14.01
Calcium sulphate	1.40
Loss, etc	.15
	100.00

McMillan.—At McMillan the schoolhouse well has a depth of 80 feet and an altitude of 785 feet. The water is from sand under clay. The well at the cooperage company's mill, on ground 35 feet lower, is 60 feet in depth and has a head of —16 feet.

Manistique Lake.—North of Manistique Lake are several wells nearly 100 feet in depth. One at the schoolhouse in sec. 29, T. 45 N., R. 12 W., is 96 feet and has a head of —60 feet. It entered limestone at 40 feet. Jerry Holland has a well on the eastern side of section 30, which is 85 feet deep and enters limestone at 18 feet. The head is —20 feet. Across the road, in section 29, at the residence of Charles McKenna, is a well 86 feet deep, on ground about 35 feet higher than the Holland well. It has a head of —56 feet and entered limestone at 40 feet. John Richards has a well in the southern part of section 21 with a depth of 76 feet and a head of —68 feet. It penetrated clay for 12 feet and sand for 64 feet, striking rock at the bottom.

A well east of Little Manistique Lake on the farm of J. Fyne, in sec. 17, T. 45 N., R. 11 W., with a depth of 58 feet, has a head of only —7 feet. It penetrated clay 40 feet, below which was a sandy gravel.

MACKINAC COUNTY.

Wells on the Niagara limestone, in southeastern Mackinac County, are often sunk to depths of 60 to 75 feet, and in most cases there is little rise of the water.

Palms.—At Palms (Kenneth post-office) are two wells 108 and 117 feet in depth, made by W. J. Ross, which have an altitude of 795 feet and a head of —35 feet. Another well at Leonard's mill, at an altitude of 770 feet, is 75 feet deep and has a head of —8 feet.

Ozark.—On a limestone hill east of Ozark, a well having an altitude of about 875 feet, reached a depth of 100 feet. Farther south, near Allenville, wells are difficult to obtain, because of the large amount of shale in the Monroe beds, and borings 100 to 150 feet are not rare.

Lewis and Rex.—In wells in the vicinity of Lewis and Rex, water is obtained at very shallow depths, although the altitude is about 860 feet. Those at Lewis are from sand at about 16 feet. Some near Rex enter rock at 10 feet, but others are entirely from sand.

Gilchrist.—At Gilchrist, at an altitude of 780 feet above tide, the railroad company made a well 1,180 feet in depth, which entered rock at 80 feet and has a head of —70 feet.

West end of county.—From Millecoquins Lake southwestward past Engadine and Gould to Corinne nearly all the wells enter rock at slight depths. The shallowest are about 40 feet and the deepest over 200 feet, the common depth being about 80 feet. The water seldom rises to more than 40 feet below the surface. A test boring made at Corinne in 1888, for the purpose of obtaining a flowing well, reached a depth of 180 feet and had a head of —25 feet, or 748 feet above tide. A well at Ferguson's store, in Gould, is 116 feet deep and has a head of —12 feet, or 724 feet above tide. The majority of wells around Corinne and Gould are 65 to 80 feet in depth. Deep flowing wells at Engadine have already been discussed (p. 43), and also the flowing well at Deuels Lake (p. 43).

SCHOOLCRAFT COUNTY.

Seney.—At Seney wells were made some years ago, with a depth of 110 to 115 feet, which obtained a strong supply but not a flow.

Germfask.—East of Germfask are wells about 80 feet deep, on the Stafford farm, in sec. 12, T. 44 N., R. 13 W., with a head of —45 feet. A well on Thomas Kennedy's farm, on section 14 has a depth of 70 feet and very little rise of water. A neighboring well at S. Burns's residence, on a high ridge in section 15 has a depth of only 14 feet.

Blaney.—The William Mueller Lumber Company, of Blaney, sunk a well 214 feet for the purpose of procuring a supply for waterworks, but an insufficient and unsuitable supply was obtained. The water tastes "like bog ore." The supply is partly from a depth of 42 feet and partly from near the bottom of the well. The head is about 40 feet below the surface. There were 113 feet of drift and 101 feet of shale. The following drift beds were penetrated: Clay loam and sand, 15 feet; quicksand, 26 feet; gravel, 4 feet; blue bowlder clay with sand streaks, 68 feet.[a]

Manistique.—On a table-land east of Manistique wells are 30 to 60 feet in depth without reaching rock. The deeper wells are near the edge of the table-land, and are reported to be entirely through sand.

Hiawatha.—In the Hiawatha settlement, about 12 miles north of Manistique, wells are 40 to 65 feet in depth, through gravel and sand, and there is very little rise of water, the ground-water table being about 40 feet below the surface, or near the level of the small lakes which occur in that region in basins in the gravel plain.

Indian Lake.—On each side of Indian Lake, from a point near Manistique to Cooks Mill, is a limestone district in which wells are often 50 to 75 feet in depth, and have very little rise of water, the ground-water table being near the level of Indian Lake.

DELTA COUNTY.

Garden Peninsula.—On Burnt Bluff, on Garden Peninsula, are two wells 228 feet in depth, which have a head of —203 feet, which is about at the Lake Michigan level. Rock was entered at 3 feet. Several wells in that vicinity are 100 to 140 feet in depth. Rock is usually entered at a depth of 30 feet or less on Garden Peninsula, and in some cases wells are carried to 25 to 30 feet below Lake Michigan level before a strong supply is obtained[b].

St. Jacques.—At St. Jacques the hotel well is 35 feet in depth and obtains a supply from gravel under a bed of sandy loam. Two dug wells near the hotel are only 26 feet in depth,

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[a] Data furnished by George W. Gray, driller, Cooks, Mich.
[b] Data on Garden Peninsula furnished by George W. Gray, driller.

but a well one-fourth mile east on slightly higher ground is 65 feet deep. The altitude is 15 to 25 feet higher than at the railroad station, or 630 to 640 feet above tide.

Ensign.—At Ensign rock is struck at about 10 feet, but wells are usually obtained at the base of the drift, the rock being a shale with very little water.

ALGER COUNTY.

From the head of Little Bay de Noc northward to Lake Superior is a district in which rock is found at shallow depth, usually less than 20 feet, and wells are obtained either at the base of the drift or at a moderate depth in the rock, a well more than 40 feet in depth being rare. The altitude near the head of Little Bay de Noc is only about 600 feet above tide, but on the brow of the calciferous escarpment in the vicinity of Rumely, Lawson, and Carlshend it is 1,050 to 1,150 feet, yet the water table is sufficiently near the surface to furnish wells at very slight depth.

MENOMINEE COUNTY.

The drift is also of moderate depth west of Little Bay de Noc and Green Bay, in Delta and Menominee counties, and wells are usually obtained at the base of the drift or in the upper portion of the rock at depths of 40 feet or less. The drift is a sandy or clayey loam with thin beds of clear gravel or sand associated with or underlying it.

MARQUETTE COUNTY.

In eastern Marquette County, from Little Lake northward to Harvey and Mangum, is a belt of very heavy drift in which wells 90 to 200 feet in depth have not reached rock, while a boring to test for iron ore near Little Lake found rock at a depth of about 250 feet. A well at S. C. Miller's, in the southwestern part of sec. 35, T. 47 N., R. 25 W., at an altitude of about 1,150 feet above tide, is 205 feet in depth, and strikes water at 191 feet. It was mainly through sand, though there is a little clayey material near the surface. The water does not rise above the level at which it was struck. Mr. Miller has a shallow well only 18 feet in depth, which gives out in dry seasons. A neighboring well on the farm of James Kindlen is 184 feet in depth; in it the water stands at 164 feet below the surface. The altitude is slightly lower than at Miller's, being probably 1,130 feet above tide. This well is thought to have struck bed rock at the bottom, though it may perhaps have been merely a cemented crust in the drift, for the Miller well penetrated a crust at 186 feet. Both these deep wells are on a prominent moraine, about 2 miles northeast of Sands station, on the Chicago and Northwestern Railway. A few miles farther north, on the same moraine, a well was made some years ago at Frazier's lumber camp, in sec. 21, T. 47 N., R. 25 W., 190 feet in depth, which penetrated only gravel and sand. It is at an altitude of over 1,200 feet. Near this well in the southwestern part of section 16, at an altitude only a few feet lower, is a shallow dug well having water standing within 10 feet of the surface, thus repeating the conditions noted at the Miller wells.

On a moranic ridge west of Mangum are several wells 80 to 90 feet deep on the farms of James Barry, Carl Whitler, William Preab, and Mr. Huebner. They penetrate a large amount of white sand, but in some cases pass through a thin bed of bowlder clay at the surface and another near the bottom of the well.

In the vicinity of Skandia wells are 30 to 50 feet in depth and in some cases enter rock near the bottom.

PUBLIC WATER SUPPLIES.

About half the population of the Northern Peninsula is found in cities and villages provided with public water supply. The sources of supply set forth in the table below are chiefly from surface water, only a few villages drawing a public supply from wells. This is a natural condition, in view of the contiguity of large bodies of fresh water, and, in most cases, the supply is fully as good as can be obtained from underground sources. The principal danger appears to be that of sewage contamination around the intake pipes, and this may be guarded against by placing these pipes out of reach of the sewage.

Municipal and institutional water supplies.

Town.	Population, 1900.	Ownership.[a]	Source.	System.[b]	Remarks.
Atlantic mine	±3,000	P.	Creek and well		Partial domestic supply from well.
Baraga	1,185	P.	Keweenaw Bay		
Bay Mills	1,000	P.?	Whitefish Bay	T.	
Beacon	±1,500	M.?	(?)		Hydrants for fire.
Bessemer	3,911	M.	Springs and impounded water.		Springs for domestic use.
Blaney	± 300	P.	Creek		Operated by lumber company.
Crystal Falls	3,231	M.	Impounded water		Also supplies Vulcan.
Dollar Bay	±1,500	P.			Partial distribution for employees of Lake Superior Mining Co.
Escanaba	9,549	P.	Little Bay de Noc	D.	Filtration works planned.
Ewen	500	M.	Flowing wells		
Garden	465	M.	Rock wells, 104-220 feet		Partial system.
Gladstone	3,380	M.	Little Bay de Noc	D.	
Grand Marais	2,000	M.	Lake Superior	D.	
Hancock	4,050	M.	Filter gallery	R.	Manual American Waterworks.
Houghton	3,359	M.	Springs	R.	Reservoirs, high pressure and low pressure.
Iron Mountain	9,242	P.	Infiltration wells	R.	The wells are developed springs.
Iron River	1,482	M.?	Iron River		
Ironwood	9,705	P.	Montreal River	T.	Manual American Waterworks.
Ishpeming	13,255	M.	Small lake	G. and D.	Do.
Lake Linden	2,597	M.	Well and creek	D.	Do.
L'Anse	620	M.	Spring-fed creek	G.	Do.
Laurium and Red Jacket.	10,311	P.	Lake Superior	D.	Do.
Mackinac Island	665	P.	Lake Huron	R.	
Manistique	4,126	M.	Indian Lake	G. and D.	Runs to reservoir in city.
Marquette	10,058	M.	Lake Superior	D.	High parts of city have private tanks.
State prison	[c] 300	St.	Small stream		
Menominee	12,818	P.	Green Bay	D.	Manual American Waterworks.
Munising	2,014	M.	Springs, and Lake Superior.	T.	Lake Superior for emergency.
Negaunee	6,935	M.	Teal Lake	D.	Manual American Waterworks.
Newberry	1,421	M.	Tubular wells	D.	Data given above.
State asylum	[c] 600	St.	do	T.	Do.
Norway	4,170	M.	Impounded water	R. and D.	Manual American Waterworks.
Ontonagon	1,267	M.	Lake Superior	T.	Do.
Palmer	799	P.	Springs and wells	WM.	Partial system.
Quinnesec	600	M.	Mine water		Chiefly fire protection.
Rapid River and Masonville.	±1,200	M.	Rock wells, 275 feet	D.	Fire hydrants on flowing wells.
Republic	±2,500	M.?	Springs and lake		Installed in 1906.
Rockland	±1,000	P.	Springs	WM.	Partial system.
St. Ignace	2,271	M.	Lake Huron	T.	
Sault Ste. Marie	10,538	M.	Whitefish Bay	T.	Base of tank 114 feet above Lake Superior.
Stambaugh	695	M.	Iron River	D.	Manual American Waterworks.
Vulcan	2,000		Impounded water		Supplied from Norway.
Wakefield	1,191	M.	Sandy Lake		Fire protection.

[a] Abbreviations under ownership as follows: P=Private; M=Municipal; St.=State.
[b] Abbreviations under system as follows: T=Tank or standpipe; R=Open reservoir; G=Gravity; D=Direct pressure; WM=Windmill.
[c] Population in 1906.

QUALITY OF WATER.

Analyses of Lake Superior water have been published by the State geologist in the annual report for 1903, pages 113 to 118, and analyses of water from Green Bay on pages 119 to 120, while several analyses of Lake Michigan water appear in Water-Supply Paper No. 31 of the United States Geological Survey. The sanitary analysis of a flowing well at Menominee also appears in the annual report of the State geologist for 1903, pages 121 to 122. It appears from these analyses that the hardness of the waters in Lake Michigan and Green Bay is about twice that of Lake Superior, being 7° to 9° or more on Clark's scale, while on Lake Superior it is only about 3° in several of the analyses.

DRAINAGE OF WET LANDS IN ARKANSAS BY WELLS.

By A. F. CRIDER.

INTRODUCTION.

The disposal of surface waters and sewage in level countries where there is insufficient natural drainage, has long been a serious problem, and one that is becoming more pressing as the country becomes more thickly settled.

The method of drainage into the underlying subsoil by means of wells is not new, although little practiced in the United States. It has long been successfully used in the low provinces of France, and it was tried in Michigan as long as twenty-five years ago. Here, however, it was found to be impracticable, at least so far as the subsoil and shallow wells were concerned. Later, success was attained by the use of deep wells. Such wells will often penetrate sandy strata into which the water from overlying strata can be drained, thus lowering the ground-water level. In the Coastal Plain, where there are numerous porous strata of sand alternating with beds of clay, the possibility of reclaiming swampy districts by such well drainage is promising and at least deserves a thorough test.

WELL DRAINAGE IN OTHER STATES THAN ARKANSAS.

DRAINAGE BY WELLS IN MICHIGAN.

On the retreat of the glaciers a large part of Canada and the northern United States was left covered with glacial accumulations. In places large areas were left with a very irregular surface, marked by numerous sink holes, ponds, and lakes. The glaciated area, in places, had little relief, so that many of these ponds and lakes are still undrained.

In the spring the heavy rains and melting snows fill these undrained depressions to a depth depending on the area drained and the amount of precipitation. Many of the larger ponds contain more or less water throughout the year. The soil in these depressions is very fertile, and when drained becomes of great value for farming. An attempt was made about twenty-five years ago, in Parma Township, Jackson County, Mich., to drain one of these depressions into the subsoil underlying the surface hardpan. The attempt failed, but within the last few years a large number of ponds in Jackson County have been drained into the underlying porous strata by means of deep wells. The methods used and results obtained have been described by Robert E. Horton in Water-Supply Paper No. 145, pages 30 to 39. Mr. Horton describes a deep-drain well on Fred Watkins's place in Parma Township. The well is located in the center of a pond, which drains about 35 acres of sloping tilled land of permeable gravelly loam. The water covered an area of about 2½ acres, and rarely dried up. When first drilled, the well was stopped in the first water bed at a depth of about 90 feet, and the unprotected open pipe was allowed to project upward in the water near the surface. The water was drawn down very rapidly at first, but was soon greatly checked by organic material which clogged the pipe and perhaps the water bed at the bottom of the well. Two months of flow failed to drain the pond. This result being unsatisfactory, the well was drilled to a depth of 170 feet and the top of the pipe protected with a screen. In a short time the pond was completely drained.

DRAINAGE BY WELLS IN GEORGIA.

During the summer of 1903 Mr. S. W. McCallie, in cooperation with the United States Geological Survey, made some valuable experiments in Quitman, Ga., on the drainage of sewage into deep wells.

A well was bored to improve the city's water supply. At a depth of 123 feet the drill entered an apparent opening in the limestone 6¾ feet deep and the water immediately rose to within 77 feet of the surface. Efforts were made to lower it by continuous pumping, but without success. It was likewise found that large volumes of water could be forced into the well without raising the static head above 77 feet below the surface. The well was then bored deeper and a second water-bearing horizon encountered at a depth of 321 feet.

To test the carrying capacity of the upper water-bearing stratum, a second well, 6 inches in diameter, was bored near Russell's pond, a stagnant pool, the water from which was drained into the well. About one-half million gallons of water were drawn down in a few hours without raising or lowering the static head of the water, which stood at 77 feet below the surface.

The town authorities concluded that the underground water course could be used for carrying away the city's sewage. The results of an elaborate experiment carried on by Mr. McCallie, however, proved conclusively that a pollution of the other wells would result from such a procedure, and the proposed disposition of the sewage was therefore abandoned.

DRAINAGE BY WELLS IN ARKANSAS.

In the Coastal Plain of northeastern Arkansas are millions of acres of flat lands, occupied by swamps, old sloughs, and shallow lakes. Thousands of acres of this area are covered with water in the spring and early summer, and thereby made worthless for agricultural purposes. Attempts have been made in a few instances to drain small portions of this area by means of deep wells, but the difficulties encountered have not been overcome, and the success of the work is still much in doubt.

TOPOGRAPHY OF THE AREA.

The area of northeastern Arkansas, extending from the Paleozoic hills to Mississippi River, is a level plain, with a minimum elevation of about 100 feet at the mouth of Arkansas River on the south and of 296 feet near the Missouri line. The monotony of the surface is broken by Crowleys Ridge, a low swell, from 1 to 12 miles wide, extending from Commerce, Mo., to Helena, Ark. The highest points of the ridge are about 120 to 140 feet above the flat lands on either side.

West of the ridge the country is diversified with wooded lands, prairies, and broad swells 15 to 20 feet above the general level. These low ridges have a general north-south direction roughly parallel to Crowleys Ridge. The region is drained by White River and its tributaries, Black, Cache, and L'Anguille rivers. East of the ridge the country is much flatter. St. Francis and Mississippi rivers are the only streams of any importance. The St. Francis and its tributaries are very crooked and have very little grade. In many places near the Missouri line St. Francis River is little more than a series of broad lakes. The country is known as the "sunken lands" of St. Francis River. The numerous lakes were caused by the earthquakes of 1811 and 1812.

After a long rainy season the country east of Crowleys Ridge is completely inundated. There is not enough drainage to carry off the water in rainy seasons, so it collects in the lower lands and often remains for months. The great amount of water is a hindrance in the spring to putting in the crops, and occasionally destroys them after they have become more or less mature.

CHARACTER OF SURFACE STRATUM.

A large area adjacent to Crowleys Ridge on the west and a narrow fringe on the east have a thin surface stratum of light-gray sandy clay nearly impervious to water and containing numerous nodules of limonite. Along the present streams and old water courses of the entire region, the limonitic hardpan has been removed or covered with stream alluvium, consisting of fine silt and sand. The clay, therefore, where not present as a surface stratum, spreads over the region as a subsoil. The nodules of limonite and the impervious clay soils have given rise to the terms "buckshot" and "slash lands." On the higher ridges, the clay loam is very similar to the Columbia formation, and is doubtless the reworked product of the loess and Columbia, which are present on the top and sides of Crowleys Ridge.

CHARACTER OF THE UNDERLYING STRATA.

The material underlying the surface hardpan consists of interstratified beds of sands and clays. The following are typical well sections, which show the relations of the strata underlying the surface clay:

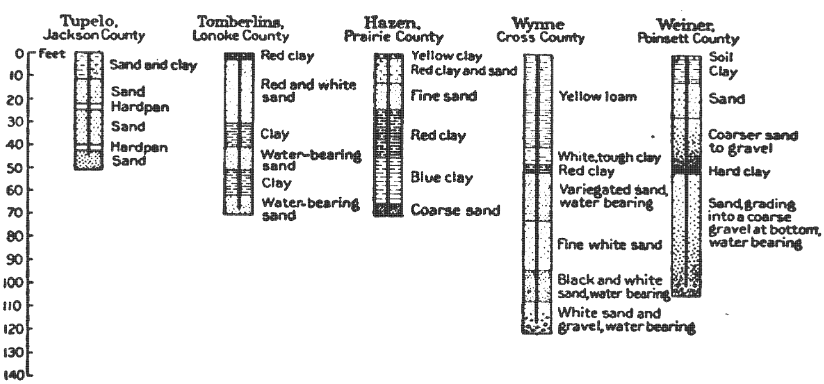

FIG. 4.—Well sections west of Crowleys Ridge in Arkansas, showing the variation of the strata and the source of the well waters in different localities. The Tupelo section is after Purdue.

DEPTH OF STANDING SURFACE WATER.

The depth of the water on the lowlands depends on the amount of rain and the elevation of the area compared to the surrounding country.

The average amount of rainfall of northeastern Arkansas is usually between 40 and 50 inches a year. After weeks of continuous rain, especially in the spring, the streams become swollen and the water often covers the lowlands to a depth of 1 to 10 feet.

In May and June, 1905, much of the country between Blytheville and Jonesboro was covered with water to a depth of from 6 inches to 2 feet. West of Crowleys Ridge, between Jonesboro and Wynne, is a flat swampy area which is usually covered with a thin sheet of water that rarely dries up early enough in the spring to permit cultivation. In this region deep-well drainage has been tried.

HEIGHT OF THE WATER TABLE.

The height of the water table varies in different parts of the area and in different seasons of the year. There are in most places three water horizons, the first at a depth of 18 to 20 feet, the second at from 30 to 40 feet, and the third at from 50 to 60 feet. Water in most places is obtained at the base of the surface clay loam.

During the dry season of the year the water rises in the wells to within 12 to 15 feet of the surface; in the wet season it stands within 3 to 5 feet of the surface, and occasionally rises to the top.

NUMBER OF WELLS NECESSARY TO DRAIN AN ACRE.

The well owned by Fred Watkins, in Parma Township, Jackson County, Mich. (see p. —), drains about 35 acres; but this is in the center of a depression, and the water has a tendency to collect about the mouth of the well. In Arkansas the conditions are somewhat different. The entire country on which the water stands is practically level. It is hardly possible that one well will drain so large a territory where the area is level. It is estimated by an experienced well digger at Harrisburg, Ark., that it will require about four 12- to 16-inch wells to drain an acre, or one well to each quarter of an acre. This estimate, however, is doubtless too large. A fairer estimate would be one 12- to 16-inch well to the acre, and this would bring drainage within reach of all.

After a period of four to six months the wells are apt to become clogged and cease to carry off the water, but the silt and débris can often be removed from a 12- or 16-inch well with a sand bucket and the well be restored to its former carrying capacity.

COST PER ACRE.

The cost of putting down the wells depends, of course, on their depth. A 12- to 16-inch well can be bored and curbed with wood for 50 cents per foot. This is the cheapest well, and is doubtless as good as any other for drainage purposes. Wells of this class usually can easily be cleaned out with a sand bucket when they become clogged with silt and vegetable matter.

The first sands encountered, immediately underlying the surface hardpan or clay, are sufficiently porous to carry off the surface waters. The hardpan varies in depth from 10 to 40 feet over the larger part of the wet areas. The minimum cost, therefore, of a 12- to 16-inch well, curbed with wood, is $5 and the maximum cost $20. There must be added to this the cost of tile, ditching, and laying of tile. The cost of tile varies greatly, according to its size and the distance from the factory. An average price for all sizes is about $12 per thousand. But the smallest tile would be large enough to carry off the water, and the price per thousand would therefore be much less than $12. So far as known no tile has been used in carrying water to the drain wells, and the amount of tile necessary to drain an acre is not known.

VALUE OF DRAINAGE.

When the land is drained it is very desirable for corn, cotton, and alfalfa. Similar land is found in southeastern Missouri east of St. Francis River, where a large area has been drained by means of canals. Dredge boats were used to open up the main canals, at State and national expense, and the landowners then cut small canals to drain into the larger ones. The land, which could have been bought for from $1.50 to $3 an acre before it was drained is now selling at from $50 to $100 an acre. Similar results could be expected in Arkansas if deep-well or surface drainage could be perfected. Before the land is drained it is practically worthless, except in very dry seasons. After it is thoroughly drained it will produce to the acre from 75 to 100 bushels of corn or four to five cuttings of about 1 ton of alfalfa which readily sells for $10 a ton.

RESULTS OF EXPERIMENTS.

Well drainage in Arkansas has been considered impracticable, owing to the large amount of clay in the surface soil, which, when taken into solution and permitted to enter the well, silts up the water-bearing sands and prevents further escape of the water. The experiments made have not on the whole been successful. No effort has been made to overcome the difficulty, but it could be obviated by digging a series of settling pools into which the water from the surrounding land could be drained and permitted to settle before it entered the well. The number of pools would depend on the amount of clay in the soil. The greater the amount of clay the greater the amount of material which would be taken into solution and the more settling it would require to clear the water. Doubtless two or

three pools would be a sufficient number to clear the water. The water from the surrounding land should be permitted to enter only one of the pools and then should be conveyed to the second and third by means of pipes or open troughs near the tops of the pools, the water flowing out of a pool on the opposite side from which it entered. In this way it would have a chance to settle. The well should be located in the third or last pool, with the open pipe projecting upward near the surface of the water. The well should be curbed to prevent the water which enters it from becoming impregnated with clay.

SANITARY EFFECTS OF WELL DRAINAGE.

In the United States few experiments have been made in regard to the sanitary effects of draining surface waters into underground water beds, the only authentic experiment being that made by Mr. S. W. McCallie at Quitman, Ga., in which he found that there was an intimate relation between wells in the same vicinity deriving their waters from the same geologic horizon, and that the pollution of the first water-bearing bed at a depth of 123 feet of the surface likewise contaminated the water in the second bed at a depth of 321 feet.

Large bodies of stagnant water highly impregnated with organic matter should not be drained into underground water horizons which supply the wells of a community with drinking water. It is quite probable that in northeastern Arkansas the surface water could be drained into the first or second sands from the surface, and the drinking water be obtained from a much lower horizon without any injurious effects.

TOTAL AMOUNT OF FREE WATER IN THE EARTH'S CRUST.

By Myron L. Fuller.

INTRODUCTION.

The problem of the amount of water in the earth's crust is of paramount interest to drillers and others seeking deep underground supplies, as well as to those interested in the problems of underground circulation as affecting mining. Probably no other question is so frequently asked in the field as that in regard to the water zone which most people suppose to exist somewhere below the surface and which they invariably believe will always be found if a well only "goes deep enough." The present paper considers the subject of the total free water in rocks of various types, incidentally showing the absence of the immense "underground lakes" of popular imagination.

By free water is meant the water which occupies the joints, solution passages, pores, or other openings of the rock. It should be carefully distinguished from the chemically combined water in the minerals of the rocks. The free water is present in the form of a liquid which possesses a more or less definite circulation even in the densest rocks, while the water in combination is not in liquid form, but is a part of the mineral compound itself. The free water should also be distinguished from the available water, since some materials, like clay, hold great quantities of water and yet often give up only insignificant amounts. It is in fact possible for a rock to hold 35 or 40 per cent of water and yet yield almost none to a pump; that is, almost none of its water is available.

From the nature of the case the discussion necessarily deals with average conditions, as local conditions vary so greatly and so rapidly that generalizations of value can not be made from isolated regions. While it is believed that the present estimate of the amount of underground water is fairly close for the earth as a whole, it is to be expected that the amount in certain materials and at certain localities will depart considerably from the figures given.

PREVIOUS ESTIMATES.

ESTIMATE OF DELESSE.

Of the many estimates of the total ground water that of Delesse [a] is among the most widely quoted, possibly because of the striking results reached. The estimate is based on the assumption that the water in rocks diminishes from 5 per cent of their weight or 12½ per cent of their volume at the surface to nothing at a depth of 6 miles, and that water may exist in liquid form at a temperature of 600° C., which was considered as equivalent to a depth of 18,500 meters. Under these conditions the amount of ground water is calculated as 1,175,089 million million cubic meters or 1,530,000 million million cubic yards, which is equivalent to $\frac{1}{521}$ of the earth's volume or to a sheet water over 7,500 feet thick surrounding the earth.

ESTIMATE OF SLICHTER.

Of the attempts made in America to estimate the total ground water since a definite knowledge of the porosities of rocks has been available that of C. S. Slichter [b] is among the most notable. The amount postulated, though less than half that of Delesse, is still immense, being equivalent to a uniform sheet from 3,000 to 3,500 feet in thickness.

[a] Delesse, Achille, Bull. Soc. géol. France, 2d ser., vol. 19, 1861, p. 64.
[b] Motions of underground waters: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, p. 14.

As a basis for his estimates Slichter has taken the results of L. M. Hoskins,[a] accidentally crediting them, however, to C. R. Van Hise,[b] whose statements were in reality based on the calculations of Hoskins. These calculations, to summarize them briefly, tended to show that cavities can not exist at depths of more than 6,520 meters when water free, or, where occupied by waters under hydrostatic pressure, at depths of more than 10,350 meters.

Slichter says:

The writer estimates the entire amount to be about 565,000 million million cubic yards, or about 430,000 million million cubic meters. He has arrived at this result by considering that the geologic limit of the existence of ground water is at an average depth of 6 miles below the surface of the land and 5 miles below the floor of the ocean. The land surface and water surface he has assumed to be 52,000,000 square miles and 144,700,000 square miles, respectively. The average pore space of the surface rocks which is occupied by water or moisture he has taken as 10 per cent of their total volume. He believes that the estimate of 10 per cent is too large rather than too small. It forms, however, a convenient basis for the estimates.

According to these estimates, the total amount of underground water is sufficient to cover the entire surface of the earth to a uniform depth of from 3,000 to 3,500 feet. Assuming a mean depth of the ocean of 12,000 feet leads to the conclusion that the total amount of oceanic water is about 1,800,000 million million cubic yards, so that the total quantity of ground water is nearly one-third the amount of the oceanic water.

ESTIMATE OF VAN HISE.[c]

Van Hise's estimate is the most moderate yet made. Taking one-fifth of Dana's estimate[d] (2.67 per cent of the weight of the rock) of the amount of water in the rocks at the surface and assuming the pore space to diminish to zero at the lower limit of the zone of fracture at 10,000 meters, he obtained an average porosity of 0.69 per cent, which would be equivalent to a sheet 69 meters, or 226 feet, thick over the continental areas. No computations were made regarding the oceanic areas.

ESTIMATE OF CHAMBERLIN AND SALISBURY.

The estimate of T. C. Chamberlin and R. D. Salisbury,[e] while not based on anything like a complete analysis of the problem and not claimed to be of the nature of a measurement, is of interest in connection with the discussion.

The estimate is based on the assumption that the average porosity of rocks is between 5 and 10 per cent of their volume at the surface and decreases to 0 at a depth of 6 miles. With the lower value, giving an average porosity of 2½ per cent, the water in the earth would be equivalent to a layer 800 feet deep over its entire surface, while with an assumed porosity of 5 per cent it would form a layer 1,600 feet in depth.

FACTORS IN ESTIMATES OF UNDERGROUND WATERS.

GENERAL STATEMENT.

As a more intimate knowledge of the occurrence of subterranean waters of the United States has been obtained through the work of the division of the Geological Survey dealing with underground waters, it has become clear that the problem is not as simple as has been postulated by previous writers. Not only are there certain factors affecting the problem which are not taken into account in earlier computations, but a more careful analysis of the data appears to show that a closer approximation can be made in the values of the factors used. It is believed that the pore space of the rocks has been overestimated and that the assumptions as regards complete saturation are incorrect. This has resulted, it is thought, in estimates considerably in excess of the true amount.

The more important factors affecting the estimates are considered in detail below. Nothing need be said in regard to temperature, which was once thought to be a limiting factor to the penetration of water, as it has been shown and is now well known that the increase

[a] Flow and fracture of rocks as related to structure: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 845–875.

[b] Principles of North American pre-Cambrian geology: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 593.

[c] Van Hise, C. R., a treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 128–129, 570–571.

[d] Dana, J. D., Manual of Geology, 4th ed., 1895, pp. 205, 311.

[e] Geology, vol. 1, pp. 206–207.

of pressure is sufficient to prevent the conversion of the water into steam at temperatures under the critical temperature, beyond which point, although a gas, the behavior of the water, so far as its relations to the rocks are concerned, differs but little from its behavior below the critical temperature, since it is far below the depth of critical pressure.

POROSITY OF ROCKS.

The absorptive capacities of rocks are commonly expressed in terms either of porosity or of the ratio of absorption. The first may be defined as the percentage of pore space, while the second is the ratio between the weight of water absorbed and the weight of the rock tested. The relationship between porosity and ratio of absorption is not constant, but varies with the specific gravity of the rock. The tendency of the most advanced workers is to state porosity rather than the ratio of absorption, but in the table given below, with the exception of the determinations credited to Buckley, all figures represent recalculations from the ratios of absorption. The determinations of Buckley are the most recent and are probably the most accurate of those quoted, but being limited to the rocks of a single State are in some ways not so representative as those taken from the book of Professor Merrill, in which the results, which appear to have been the work of several different laboratories, cover a wider range of rock types. Unfortunately part of the ratios of absorption are expressed as decimals and part as common fractions, but no explanations are given. The common fractions only have been used in the present computations, as the decimals taken as they are expressed in the book give results manifestly incorrect.

In connection with the figures credited to Delesse and Geikie it should be stated that, in the absence of statements of the specific gravity of the specimens tested, this has been assumed throughout to be 2.65.

Porosity of rocks.

Rock.	Authority.	Number of tests.	Minimum.	Maximum.	Average or mean.	Remarks.
Granite, schist, and gniess.	Buckley [a]	14	0.019	0.56	0.16	Wisconsin rocks only.
Do	Merrill [b]	22	.37	1.85	1.2	
Gabbro	do	1			.84	
Diabase	do	2	.90	1.13	1.01	
Obsidian	Delesse [c]	1			.52	Specific gravity not given.
Sandstone	Buckley [a]	16	4.81	28.28	15.89	Mainly brownstones.
Do	Merrill [b]		3.46	22.8	10.22	
Quartzite	do	1			.8	
Do	Giekie [d]				.21	Specific gravity not given.
Slate and shale	Delesse [c]	2	.49	7.55	3.95	
Limestone, marble, and dolomite.	Buckley [a]	11	.53	13.36	4.85	Wisconsin rocks only.
Chalk	Geikie [d]				53	Specific gravity not given.
Oolite	Merrill [b]	8	3.28	12.44	7.18	Indiana stone only.
Gypsum	Geikie [d]		1.32	3.96	2.64	Specific gravity not given.
Sand (uniform)	King [e]	Many	26	47	35	Theoretical porosity; actual results similar.
Sand (mixture)	do	do	35	40	38	
Clay	do	do	44	47	45	
Do	Geikie [d]				53	Specific gravity not given
Soils	U.S. Dept. Agr	Many	45	65	55	Common range.

[a] Buckley, E. R., Building and ornamental stones (of Wisconsin): Bull. Wisconsin Geol. Survey No. 4, 1898, pp. 400-403.
[b] Merrill, G. P., Stones for Building and Decoration, Appendix.
[c] Delesse, A., Bull. Soc. géol. France, 2d ser., vol. 19, 1862, p. 64.
[d] Geikie, A., Text-book of Geology, vol. 1, p. 410.
[e] King, F. H., Principles and conditions of the movements of ground water: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, pp. 209-215.

THICKNESS OF SEDIMENTS.

Evidence of sections.—From the nature of their occurrence it is usually very difficult to obtain any accurate idea of the thickness of the sedimentary rocks, especially in the flatter portions of the surface where the outcrops are often covered by drift or by mantles of residual soil. In mountainous regions, especially where the rocks are strongly folded or upturned in great monoclines, immense thicknesses are sometimes exposed. A single section recently measured by C. D. Walcott in Montana shows about 40,000 feet of pre-Cambrian shales and limestones. The sediments in eastern Pennsylvania have also been estimated by some to attain a similar thickness, but in the western portion of the State they are probably not much over a mile thick. In Europe the sediments in the Alps are estimated by Judd to have a thickness of nearly 8 miles, and it is not impossible that as great or greater thicknesses are exposed in other mountain masses.

Evidence of faults.—The evidence of faults is of interest in this connection, for by them sediments previously deeply buried have frequently been brought to the surface. The thickness exposed is generally much less than that shown in folded regions, for the greatest faults, such as those of the Appalachians of this country—one of which is estimated to have a displacement of 5 miles—are often inclined at a low angle to the horizon and the thickness of sediments elevated is relatively slight. Even if the greatest faults yet recognized were vertical the strata brought up would be thinner than in sections such as those measured by Walcott in Montana.

Evidence of borings.—While even in the case of the deepest borings only a little over a mile of sediments has been penetrated, they are of interest as furnishing accurate data concerning the underlying beds at the points at which they are drilled. The deepest wells are those sunk in Germany, South Africa, and the United States, the maximum depths reached being 6,572, 5,582, and 5,575 feet, respectively. There are, however, many deep wells in other localities.

Estimates of total thickness.—Of the various estimates of the thickness of the sedimentary beds, one of the earliest to be widely quoted was that made by J. D. Dana [a] in 1875. He estimated the thickness of the sediments over the land area as not exceeding 5 miles, which would be equivalent to 1.3 miles over the whole surface. A few years later T. Millard Reade stated [b] that a moderate estimate of the sedimentary crust of the earth is 10 miles, but on a later page [c] says it may safely be provisionally assumed that the actual average thickness of the sedimentary crust of the globe is not less than a mile, an estimate very similar to Dana's.

In 1894 G. K. Gilbert,[d] from a study of the chemical analyses summarized by F. W. Clarke [e] and of the composition of sea water, calculated the amount of crystalline rocks necessary to furnish the sodium of the ocean. His conclusions were "that somewhat more than a mile in thickness of crystalline rocks upon areas equal to all the present land of the globe must have been worked over to give our sedimentary rocks." Allowing for an increase of one-third in volume, this would be equivalent to 1⅓ miles of sediments over the land or about one-third of a mile over the whole surface. Nothing is said of the sodium locked up in undecomposed crystalline fragments in the sediments, as in the Carboniferous conglomerates and in the arkose sands of the Potomac (Cretaceous), as well as in smaller quantities in nearly all sedimentary rocks. If this was not considered in the estimate something should be added to the figures given by Gilbert, but in any case it is clear that the result would be something less than half a mile of sediments over the whole surface of the earth.

Recently F. W. Clarke has made a similar calculation on the basis of the sodium chloride in sea water, reaching the conclusion that the total thickness of the sediments, if distributed

[a] Manual of Geology, 2d ed., 1875, p. 657.
[b] Chemical Denudation in Relation to Geologic Time, 1879, p. 29.
[c] Op. cit., p. 53.
[d] The chemical equivalence of crystalline and sedimentary rocks: Am. Geologist, vol. 13, 1894, pp. 213–214.
[e] Bull. U. S. Geol. Survey, No. 78, 1891, pp. 34–42.

over the earth's surface as a whole, would be only about half a mile. The details of the calculation and the results will be published soon.

C. R. Van Hise, in his Treatise on Metamorphism,[a] after quoting previous writers, estimates the thickness of the metamorphosed sediments at 2 kilometers (1⅓ miles) over the land surface, which is equivalent to three-tenths of a mile over the entire surface of the earth.

In view of the fact that later refined investigations have shown that the thickness of sedimentary series encountered in the field has been almost invariably overestimated when first studied, it seems probable that the figures given by the earlier writers must be considered in general as representing maximum estimates, especially as considerable thicknesses of sediments have sometimes been postulated beneath the ocean deeps. The best evidence seems to show, however, that except in the continental platforms and their extensions, the deposits of the ocean may be neglected in rough computations of the thickness of sediments.

It is believed that, in view of the general tendency to overestimate the thickness of exposed rock series and the great areas in which crystalline rocks constitute the surface, the estimates postulating a thickness of sediments of from three-tenths to one-half mile over the whole earth's surface are most probable. In the present paper the writer has taken approximately one-half mile, or 2,600 feet, as a conservative estimate of the thickness of the unaltered sediments.

PROPORTIONS OF THE VARIOUS SEDIMENTS.

Summary of estimates.—A number of interesting estimates of the proportions of the various sediments have been made. Reade,[b] in his study of the chemistry of sea and river waters, estimated a thickness of 528 feet of limestone. Dana,[c] apparently from general stratigraphic data, estimated the thickness of limestone as 1,000 feet. Gilbert,[d] as a result of his chemical studies, estimated the limestones to comprise 19 per cent, the shales 42 per cent, and the sandstones 39 per cent of the sedimentary beds.

Van Hise,[e] after pointing out several sources of error in the calculations of Reade, computes the proportion of limestones on the basis of the depletion of calcium oxide in the sandstones and shales as compared with the original rocks,[f] and reaches the conclusion that an estimate of 5 per cent of the mass of sediments for limestones is as near the truth as can be made at the present time. The shales are estimated to comprise 65 per cent and the sandstones 30 per cent of the total thickness of metamorphosed sediments.

The writer's estimate.—It is believed by the writer that Van Hise's estimate of the limestone will prove to be somewhat too low, while that of Gilbert may be slightly high. In the deposits of this country, which may be taken as fairly typical, shales almost everywhere predominate over sandstones. Even in the Carboniferous rocks of the Appalachian region, where the sandstones reach a great development, they probably do not comprise more than 40 per cent of the whole. For the purposes of the present discussion the following values are assumed: Sandstone 40 per cent, shales 50 per cent, and limestone 10 per cent.

DEPTH OF ZONE OF FRACTURE.

As already pointed out (p. 60), the studies of L. M. Hoskins have shown that in rocks of ordinary specific gravities cavities free from water can not exist at depths of more than 6,520 meters, or where occupied by waters under hydrostatic pressure at depths of more than 10,350 meters. Rock-inclosed, liquid-filled cavities can, however, exist to an indefinite depth at which water and rocks are miscible in all proportions. As this is in no sense free ground water it need not be considered in the present discussion.

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[a] Mon. U. S. Geol. Survey, vol. 47, 1904, p. 939.
[b] Chemical Denudation in Relation to Geologic Time, p. 53.
[c] Manual of Geology, 2d ed., p.—.
[d] Am. Geologist, vol. 13, 1894, pp. 213-214.
[e] Mon. U. S. Geol. Survey, vol. 47, 1904, p. 941.
[f] Op. cit., pp. 990-991.

The results of drilling in sedimentary and crystalline rocks, as well as studies of deep mines, show that in all probability water does not commonly exist in the rocks under great hydrostatic pressure, although such may be exerted in an occasional crevice. It is not believed that hydrostatic waters exist, except possibly in rare instances, at depths of over 10,000 feet, and it is almost certain that water plays no part in preventing the closing of cavities and that in reality the estimate of a depth of 6,520 meters, or 20,000 feet, as the limit of the zone of open cavities is closely approximate to the truth.

Beneath the land, then, it seems safe to assume that all physical pores are closed at a depth of about 20,000 feet, but under the sea the conditions are different. The average depth of the ocean is estimated at 14,000 feet, and since the ratio of its specific gravity to that of the rocks is approximately 1 to 2.65, it follows that the pressure at a depth of 20,000 feet will be considerably less than at a similar depth on the land. In reality it is only where a depth of 28,700 feet from sea level is reached that all cavities will become closed. Of this depth, as has been seen, 14,000 feet are of water, hence the rock within the zone of fracture has a thickness of only 14,700 feet.

Assuming 17,400 feet (20,000 minus 2,600 feet, the thickness of the sediments) as the thickness of the crystalline rocks in the zone of cavities over the land (one-fourth of the earth's surface) and 14,700 feet as the thickness beneath the sea (three-fourths of the surface) we obtain an average thickness of 15,375 feet.

DEPTH OF ACTIVE CIRCULATION.

Evidence of thermal springs.—The evidence of thermal springs as to the depth of penetration of waters is of considerable interest. Notwithstanding the numerous and profound faults and the even more numerous joints, we have in this country, outside of what may be considered as igneous regions, or regions of very recent disturbance, only a few scattered examples of hot springs, the Georgia, Virginia, North Carolina, and Arkansas springs being about the only examples of note. These conditions are similar to those prevailing on other continents. If waters were freely circulating at great depths within the zone of fracture, hot springs would certainly be more common along the numerous faults or joints of the Piedmont, Appalachian, and similar regions.

Again, the temperature of the springs appears to indicate an essentially superficial origin. Tests made on wells by the writer show that with a steady and moderately rapid flow of water through a pipe with a diameter of one-half inch the change in temperature, due to a difference of 15° in that of the surrounding material, amounted to only about 1° for 1,000 feet. It is therefore clear that the temperature of the larger warm springs, if undiluted by the ingress of surface water, would be essentially that which they possessed at the point of heating. In most instances, however, there will probably be some dilution, but in no case could any copious circulation from great depths take place without its being felt in the temperature of the springs.

Springs with a temperature of over 150° F. are rare, if they occur at all outside of igneous regions. As this temperature represents only a depth of 5,000 feet on the basis of an increment of 1° to each 50 feet of depth, it is readily seen that we have ordinarily no truly deep-seated springs whatever. Springs at the boiling point would represent a depth of only about 8,000 feet. The rarity, even in igneous regions, of solfataras and fumaroles, which in some cases may be considered to represent waters approaching the surface at a temperature of more than 212°, is of significance.

Evidence of deep mines.—There are two quite diverse views held in regard to the significance of the evidence afforded by mines as to underground-water conditions, one being that they show the waters to increase in amount with depth, and the other that the circulating waters are largely of meteoric origin and are essentially superficial. This diversity of opinion is the natural result of a familiarity with a certain class of mines to the exclusion of others. In many instances the conditions as regards the ground waters are controlled by accidents of topography, especially in the case of the shallow mines, the evidence presented by which is, in fact, of slight value. In order to bring out the general underground-water conditions, the following summary of the conditions in the deeper mining districts has been prepared, together with statements of the character of the rock and topography:

Summary of ground-water conditions in deep mines in the United States.

Mining district.	Maximum depth of mines (feet).	Character of rocks.	Topographic conditions.	Underground-water conditions.	Authority (oral statements to writer, except where otherwise indicated).
Ely, Vt	[a] 1,700	Crystalline schists	On slope, 200 feet above drainage.	No water below 600 feet	W. H. Weed.
Calumet, Mich	5,000	Interbedded traps and felsitic conglomerates.	Not elevated	Water mainly in upper 500 to 600 feet. Little water in lower levels; is salty. Separated from fresh by sharp line.	A. C. Lane. [b]
Boundary Creek, Canada	800	Volcanic tuffs and some limestone; intrusives near.	Local drainage level with springs 200 to 400 feet below mines.	All dry	W. H. Weed.
Marysville, Mont	1,600	Argillite and diorite	Sidehill, 600 feet above drainage.	Most of water is above 900-foot level, although vein is open.	Do.
Elkhorn, Mont	1,800	Limestone	In valley, at drainage level.	Open solution channels to bottom, but present water mostly above 1,400 feet.	Do.
Butte, Mont	2,400	Granitic rocks	Sidehill, 400 feet above drainage.	Water is descending, reaching to bottom in cases, but with large bodies of dry rock. One at 1,600 feet, 1,200 feet in width, is absolutely dry.	Do.
Lincoln County, N. Mex. (Old Abe mine).	1,370	Calcareous shales and porphyry.	Sidehill, 500 feet above drainage.	Damp, but only a few bucketfuls raised per week.	L. C. Graton.
Leadville, Colo	1,500	Limestones, sandstones, and shales. Faulted and folded into local basins.	Deepest mines are on mountains 1,000 feet or thereabouts above drainage. Others in valleys.	Water occurs under artesian pressure in each fault basin. Mainly along faults, especially in limestone. Not much diminution with depth.	S. F. Emmons.
Cripple Creek, Colo	1,500	Closed "basin" of porous breccia in granite.	Plateau a few hundred feet above drainage.	Joints everywhere saturated with water. No diminution with depth.	W. Lindgren.
Cœur d'Alene, Idaho	1,950	Quartzite	Deepest mine starts at drainage level.	Much surface water, but no strong flows in lower levels.	F. L. Ransome.
Nevada City and Grass Valley, Cal.	2,200	Granodiorite and diabase	Undulating foothills, slightly above drainage.	Water in fissures in first 1,000 feet. Little water in lower level. Some stopes entirely dry.	W. Lindgren.
Mother Lode, Cal	2,800	Black slate and diabase, some granite.	do	Considerable water in fissures in upper 1,000 feet. Little water in lower levels, but some to bottom.	Do.

[a] 3,600 feet on incline of about 25°.

[b] Am. Geologist, vol. 34, p. 303.

Summary of ground-water conditions in deep mines in the United States—Continued.

Mining district.	Maximum depth of mines (feet).	Character of rocks.	Topographic conditions.	Underground-water conditions.	Authority (oral statements to writer, except where otherwise indicated).
Mother Lode, Cal	....	....	....	Water mainly in upper 800 feet. If this is collected balance of mine is dry. Water is hoisted with ore, pumping not being necessary.	Ross E. Browne.[a]
Bisbee....................	1,200	Limestone..................	In valley, within 200 feet of drainage level.	Much water to bottom levels. Possibly connected with faulting.	F. L. Ransome.
Globe.....................	1,200	Fault in diabase limestone and quartzite.	Hillside, 50 to 200 feet above drainage.	Not much water until mines strike faults connecting laterally with adjacent gravel-filled basin.	Do.

[a] California Mines and Minerals, California Miners Association, 1899, p. 66.

An examination of the foregoing table will show a considerable range of conditions as regards the occurrence of underground waters in mines. Certain generalizations, however, can be made. For instance, it appears that in the deep mines in the crystalline rocks of the eastern portion of the country, in which there has been no igneous activity since early geologic times, water is rarely found below the 600-foot level, the mines in some instances being practically dry from surface to bottom.

In the West, where igneous activity is more recent, the underground waters are more abundant, especially where the rocks are severely shattered, as in the Colorado mines, where much water occurs, even at the lowest levels. In the Arizona mines there is considerable water locally along faults, although the amount in other portions of the rock is not usually excessive. In the Mother Lode, California, water occurs in such slight amounts that it can be hoisted with the ore without pumping, although the workings reach a depth of 2,700 feet. In Nevada City and Grass Valley, Cal., and in some of the Montana mines the water is generally confined to the upper 1,000 feet. In other of the Montana mines, however, local water-bearing fissures or solution channels occur to depths of at least 1,600 feet. The mass of the rock, however, is relatively free from water. In three of the fifteen districts included in the table water occurs in abundance without much diminution to the bottom of the workings. In four it occurs in abundance, at least locally, up to a depth of 1,500 feet. In the remaining eight, or more than half of the deep mines, there is a general absence of water below the 1,000-foot level.

Evidence of deep borings.—The nonsaturation of the rocks at many localities is clearly brought out by deep borings. For instance, a well recently reported to the writer was sunk to a depth of over 1,000 feet in limestones near Lexington, Ky., without finding any water whatever. Another conspicuous example is the widely quoted well sunk by the Wheeling Development Company 4 miles southeast of Wheeling, in which the lower 1,500 feet were drilled in absolutely dry rock. Still other examples are the deep wells sunk at Northampton, Mass., to a depth of 4,022 feet, and the 4,000-foot well reported to have been sunk in red sandstone, etc., at New Haven, by the Winchester Repeating Arms Company, both of which failed to obtain water.

This absence of water is, moreover, not due to lack of porous rock, as shown by the two wells last mentioned and by the W. J. Bryan well No. 11, Aleppo Township, Greene County, Pa. This well is 3,397 feet deep and is cased to 3,110 feet, which represents the last water. Below the casing, however, were found the Thirty Foot, Fifty Foot, and Gordon sands, 20, 60, and 18 feet in thickness, respectively, making a hundred feet of porous, but perfectly dry sandstones. The depth at which water was found in this well is greater than the normal, no fresh water being found in many wells beyond a depth of 500 feet.

Examples of wells failing to encounter water at great depths might be multiplied indefinitely, for wells in which water has to be poured for the purposes of drilling are of everyday occurrence. The above specific citations, however, are sufficient to show the nature of the evidence. Considerable light is also thrown by wells on the nature of the crevices, including both solution passages and actual or potential openings along joint and fault planes, which are frequently encountered in rocks of all types. Frequently the joints are open or are bordered by sufficiently disintegrated material to cause the drill to "jam." Notwithstanding all this, many carry no water whatever, although others may carry considerable. The theory of the cementing of the portion of the joint planes near the surface, as advanced by G. O. Smith [a] to explain the artesian conditions in crystalline rocks near York, Me., may also offer an explanation of the absence of water in certain joints.

It is well recognized by those who have investigated the occurrence of underground waters in crystalline rocks that joints sufficiently open to constitute water passages are almost uniformly a surface feature. While it is true that a water-bearing joint was encountered at 1,160 feet in the deep Atlanta well,[b] no more were found, although the well was

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[a] Water resources of the Portsmouth-York region, New Hampshire and Maine: Water-Sup. and Irr. Paper No. 145, U. S. Geol. Survey, 1905, pp. 120-128.

[b] McCallie, S. W., Artesian-well system of Georgia: Bull. Geol. Survey of Georgia No. 7, 1898, p. 205.

continued to 2,175 feet, and in general investigators are agreed that it is not advisable to drill more than a few hundred feet into crystalline rocks in search of water. J. A. Holmes[a] concluded, from investigations in the Piedmont area of crystalline rocks in North and South Carolina, that the chance for obtaining water in deep wells was about one in ten.

The present writer has stated[b] in an earlier publication, as a result of his experience with wells in granites, gneisses, and schists, that water supplies, if obtained in these at all, are usually found within 200 or 300 feet of the surface and that it is generally useless to go deeper than 500 feet. These views have received substantial corroboration through the detailed work of E. E. Ellis on the occurrence of water in the crystalline rocks of Connecticut. His investigations, which are summarized on pages 19–28 of this report, show that practically all supplies are obtained at depths not greater than 250 feet.

Evidence of drift waters.—Not only do the consolidated rocks, as outlined in the preceding section, in many cases fail to carry water even where porous, but many very porous unconsolidated sediments are free from water, even where below the water table. Many examples were encountered in the 300 artesian localities in Michigan examined by Frank Leverett and others for the United States Geological Survey in 1904. One of the most conspicuous examples is that found in the extensive sand plain at Clinton, Mass., in which many hundreds of borings were made in connection with the construction of dikes for the big metropolitan reservoir. These borings developed a normal, gently sloping water table in sand. Below the sand an impervious clay was encountered, while below the clay was found a "hard-packed" sand destitute of water. The same feature was brought out repeatedly in boring after boring. In fact, the finding of porous deposits capable of holding immense quantities of water, but in which none whatever is actually found, is a common experience of almost every driller working in deposits of stratified drift in this country. Often they are found several hundred feet below the surface, far below the true water table or that lying above the first impervious stratum and, in many instances, much below the level of the lowest surface drainage.

Evidence of oil, gas, and associated brines.—The evidence afforded by these closely related substances is very convincing to one who has investigated their occurrence in the field. Commonly they occur in large amounts only in relatively flat rocks, their tendency being to accumulate beneath the highest point of the confining impervious roof. When this roof is broken by a prominent joint or by a fault, or when the beds are highly upturned, the hydrocarbons are no longer found in any but the smallest amounts. In other words, as soon as a passage is opened in the impervious cover, either by jointing, faulting, folding, or erosion, meteoric waters penetrate, a circulation is set up, and the oil, gas, and salt water are soon removed to the surface, appearing as the oil, gas, and salt springs so common in certain parts of the country. The oil and gas of the productive pools, so far as known to the writer, are, however, never associated with fresh waters, and although oil-bearing rocks near the surface may be invaded by fresh waters, as indicated by the oil and gas springs, the mere presence of either in pools as ordinarily known indicates an absence of circulation of meteoric waters.

Evidence of gypsum and anhydrite deposits.—Anhydrite, or anhydrous calcium sulphate, is deposited from solutions saturated with sodium chloride and calcium sulphate at 26° F., a temperature often reached in the summer seasons even in high latitudes, and, although doubtless formed under a variety of other conditions, it has probably been most commonly deposited from supersaturated sea water through evaporation.

When fresh waters are brought into contact with the anhydrite, however, water is taken on and the rocks are converted into gypsum, or hydrous sulphate of calcium. The occurrence of anhydrite in the rocks, therefore, is of special interest in connection with the problem of underground waters, pointing to the absence of circulation at the points at which the anhydrite occurs.

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[a] Trans. Am. Inst. Min. Eng., vol. 25, p. 936.

[b] Underground waters of eastern United States: Water-Sup. and Irr. Paper No. 114, U. S. Geol. Survey, 1905, p. 29.

When the beds are exposed at the surface the calcium sulphate is usually in the hydrous form, owing to the circulation of fresh ground waters. In the large quarries near Windsor, New Brunswick, however, only the upper few feet have been converted into gypsum, the great mass of the deposit still being in the anhydrous state.

Deposits have been frequently penetrated by deep borings in both this country and in Europe, but in most cases, unfortunately, no distinction is made between the anhydrous and hydrous types. At Stassfurt, however, the salt beds, which have an aggregate thickness of 1,197 feet, include thousands of anhydrite layers averaging about one-fourth of an inch in thickness and occurring at intervals of from 1 to 8 inches. At Hartlepool, in Yorkshire, borings show the limestone to be "interleaved with anhydrite and to be overlain by more than 250 feet of that deposit."[a] Again, in the Mont Cenis tunnel in the Alps over 1,500 feet of alternating anhydrite, talcose schist, and limestone are reported.[b]

From these and numerous other instances that might be cited it is clear that not only are circulating waters practically absent in many regions, even near the surface, but interstitial water is also absent. If any fresh water whatever was present in the pores of the anhydrite, hydration to gypsum would take place.

Evidence of salt deposits.—While less conclusive than that of anhydrite and of oil and gas deposits, the occurrence of salt, including sodium chloride and the more soluble potassium salts, affords considerable evidence as to the absence of circulating ground waters. The evidence of such circulating waters would be apparent at once on the thin laminæ of salt interstratified with other materials, and even the thick beds would present evidences of circulating waters if the latter occurred in any considerable amounts. So great is the rapidity of solution that even the larger masses in any but the most recent geologic formations would have long since been removed if active circulation existed. Nothing but analyses would show the presence of small amounts of interstitial water in the salt itself, but the evidence of the interlaminated anhydrite conclusively proves the absence of water in many instances.

Evidence of brines in Coastal Plain deposits of eastern United States.—Near the outcrop of most of the Coastal Plain deposits, at least of those of the coarser types, the waters are fresh, the salts in solution being practically all obtained from the containing materials. As the distance from their landward boundary increases, however, and the dip carries the beds farther below the surface, the waters often become more mineralized and in some instances are distinctly saline. At Fort Monroe and at Norfolk, Va., about 60 miles from their border, only salt waters were encountered for about 700 feet down to the granite at about 2,250 feet. Again, at Wilmington, N. C. about 115 miles from the border, the waters are salt, while at Charleston, S. C., and Savannah, Ga., wells at similar distances yield fresh waters. The depth to which circulation extends downward is not, therefore, dependent on distance from the outcrop. In reality it seems to be related, to some extent at least, to the character of the materials, being greater in prevailingly sandy beds than in more clayey beds, as at Wilmington. It is probable that leakage through vertical joints, which are common even in unconsolidated materials, has much to do with determining the distance of penetration of surface waters. The age of the strata also appears to be a factor of importance, since the more recently deposited beds, as in the vicinity of Wilmington, often show higher salinity than older beds occurring under similar conditions.

It is clear, therefore, that while active circulation may extend to considerable depths and distances in the Coastal Plain deposits, such circulation is often absent, in which case the originally inclosed sea water probably constitutes most of the water present.

Evidence of joint studies.—Recent investigations in Connecticut, made by E. E. Ellis for the United States Geological Survey, have shown that in the ordinary granites and gneisses of the region the water occurs largely in the vertical joints, which have an average spacing of between 3 and 7 feet at the surface. At depths of more than 50 feet the spacing is greater,

[a] Geikie, Text-Book of Geology, vol. 2, 1903, p. 1071.
[b] Hunt, T. Sterry, Chemical and Geological Essays, 1875, p. 335.

owing to the dying out of subordinate joints. At still greater depths there appear to be very few water-bearing joints, 250 feet being the depth fixed as a limit beyond which it is not advisable to go for water. Of the horizontal joints, almost all are confined to the upper few feet of the rock, being generally above the water table. Mr. Ellis finds that while the joints may be half an inch or more in width at the surface, they rapidly narrow with depth, and that the common width in the upper 200 or 300 feet is 0.01 inch. With a double system of joints, each with the fractures at an average distance of 5 feet from one another, there would be, even if they were completely filled with water, only 1 cubic inch of water to 125 cubic feet of rock, equivalent to $\frac{1}{215000}$ or less than 0.000046 of the mass.

If we assume an average width of the joints of 0.1 inch, which may be regarded as a maximum, the amount of water in them would still be only 0.00046 of the volume of the rock.

The joints do not always carry water to their full capacity. In fact, water in amounts sufficient to supply even domestic wells is seldom obtained at depths greater than 300 or 400 feet. The writer estimates the relative amounts of water in joints as follows:

Relation of actual water in joints in crystalline rocks to their full capacity.

Depth in feet.	Proportion of full surface capacity.
0-100	Full.
100-200	One-half.
200-300	One-third.
300-500	One-fifth.
500-2,000	One-tenth.
2,000-34,000	Practically no water.

The water present in joints in the upper 2,000 feet of the crystalline rocks is estimated, therefore, to be only 16 per cent of their capacity, or 0.000007 of the rock volume.

In the case of sedimentary rocks the joints are still farther apart than in crystalline rocks, and while they carry much water, the proportion so held to that held in the pores is very small. Caverns may be considered in the same class with joints. Being larger, they carry large amounts of water, as evidenced by the large springs, etc., coming from such passages, but even in completely honeycombed rocks the actual volume is very slight indeed as compared with the whole mass of the rock while, moreover, the circulation is essentially superficial.

The amount of water in both joints and caverns is so small compared with that in the pores of the rock itself that they have no material effect on the computations and may be disregarded.

What the amount occupying the pores may be we have no way of determining, but it is believed that not over 25 per cent of the pore space is occupied. To be on the safe side, however, 50 per cent is here assumed.

MAGMATIC WATERS.

In recent years much has been said, in connection with the discussion of ore deposits, in regard to magmatic waters as a source of vein solutions. All molten rocks reaching the surface carry water, usually in considerable amounts, and from contact phenomena it is equally evident that the same is true of many intrusive magmas, especially those of pegmatites and other acidic rocks. It is not impossible, therefore, that considerable additions to the underground-water body may take place from magmatic intrusions which fail to reach the surface, but the number of such intrusions giving off water at any one time will be exceedingly small and confined to limited areas. In a consideration of the crust of the earth as a whole their amount can be practically disregarded.

DEGREE OF SATURATION.

The theoretical absorptive capacities of rocks are essentially the same as their porosities, since, as has been shown, the amount in joints, etc., can be disregarded. In the preceding section evidences tending to show that the actual amounts are considerably less than the theoretical amounts have been adduced along a considerable number of lines. From the nature of the information available, however, it is impossible to make definite quantitative statements, but it is believed that a reasonable estimate may be made. The following is an estimate by the writer, based on his underground-water investigations for the Geological Survey:

Relation of actual water in sedimentary rocks to their full capacity.

Depth in feet.	Proportion of full surface capacity.
0-250	Full.
250-500	One-half.
500-1,000	One-third.
1,000-2,000	One-fifth.

Average per cent of full capacity, 37.

The relation of the actual water in joints to their full capacity has been discussed, it being estimated that only 16 per cent of the joint spaces are occupied. What the amount occupying the pores may be we have no way of determining, but it is believed to be much less than the capacity as indicated by their porosity.

SUMMARY.

FACTORS IN PROBLEM.

Porosity factors.—The various factors assigned in the computation of the underground waters occurring in the pores of the rocks are summarized below. In the summary the unconsolidated surface deposits are disregarded, partly for the reason that they are of inconsiderable thickness as compared with the total thickness of sediments and partly because of the fact that, while they are more porous than most of the consolidated beds, only a part of their mass lies below the water table and is saturated, the remainder being relatively water free. It is believed, therefore, that on the average the amount of water held is not greatly different from that in the consolidated sediments.

For the sandstones, shales, and limestones full porosity values are given, as in most cases the pressure has done little toward closing the pores. In the crystalline rocks, on the contrary, it is assumed that the porosity decreases from the normal at the surface to nothing at the level of no openings, hence one-half of the surface value is used in the computations. Summarizing the porosity, we have: Sandstones, 15 per cent; shales, 4 per cent; limestones, 5 per cent, and crystalline rocks, 0.2 per cent.

Saturation factors.—These have already been discussed in a preceding paragraph, but the results may be repeated as follows:

Average percentage of the theoretical capacity of stratified rocks actually taken up by water	37
Average percentage of the theoretical capacity of igneous rocks actually taken up by water	50

Thickness factor.—The average thickness of the sedimentary rocks, as outlined on page 63, is taken as 2,600 feet, while that of the portion of the crystalline rocks in which water can occur is estimated to be 15,375 feet (p. 64).

Recapitulation.—The various factors affecting the computation of the volume of underground water may be tabulated as follows:

Factors in computation of volume of underground waters.

Rocks.	Thickness.	Porosity.	Saturation factor.	Volume occupied by water.
	Feet.	*Per cent.*	*Per cent.*	*Per cent.*
Sandstone	1,040	15.0		5.25
Shale	1,300	4.0	37	1.48
Limestone	260	5.0		1.75
Crystalline rocks [a]	15,375	.2	50	1
	17,975			

[a] See p. 64.

Average per cent of rock occupied by water, 0.52.

CONCLUSION.

On the basis of these factors the total free water held in the earth's crust would be equivalent to a uniform sheet over the entire surface with a depth of little less than 100 feet (96 feet), which is only about one seventy-fifth of the amount postulated by Delesse, one thirty-fifth of that of Slichter, one-sixteenth to one-eighth of that of Chamberlin and Salisbury, and three-sevenths of that of Van Hise.

If the average depth of the ocean is 14,000 feet, its volume is equivalent to a layer 10,500 feet deep over the whole earth's surface. The underground water would, therefore, be roughly only one one-hundredth of the volume of the ocean, instead of one-half, as indicated by the figures of Delesse; one-fourth, as indicated by Slichter's estimates,[a] and one-ninth to one-eighteenth on the basis of the estimate of Chamberlin and Salisbury.

It is recognized that locally, where the sediments are very porous and of considerable thickness, several times the amount of water estimated may exist in unconsolidated deposits, or in the stratified rocks alone. There is a general tendency, however, to overestimate the amount of water in the ground owing to the impression of great volume which a large well often conveys, the fact that a large area is drained being frequently overlooked. The writer's studies of the conditions in deep wells in the United States lead him to the belief that the average amount of water present in the earth is probably under, rather than over, the amount estimated.

[a] Slichter takes 12,000 feet as the mean depth of the ocean, which would raise the underground water factor to one-third of its volume.

USE OF FLUORESCEÏN IN THE STUDY OF UNDERGROUND WATERS.[a]

By R. B. Dole.

NTRODUCTION.

This paper is an account of the use of fluoresceïn for tracing the course of subterranean waters. The methods for its application and detection are described, a brief discussion is given regarding its fitness for use under various conditions, and the results of practical experiments are cited. Nearly all of the material is taken from reports and papers on work of this character undertaken by the city of Paris. At the end is given a partial bibliography of articles relating to the subject. For copies of the original reports and discussions acknowledgment is made to the courtesy of M. Max le Couppey de la Forest, ingénieur agronome de la commission scientifique de perfectionnement de l'observatoire municipal de Montsouris.

GENERAL CONSIDERATIONS.

It frequently happens that the chemical and bacteriological examinations of a water do not show whether it is polluted. This failure results from several causes. Sometimes the polluting matter has been so diluted that the tests employed are not sufficiently delicate to find it. Frequently it is intermittent in character, so that the samples examined may have been taken at a time when no afflux occurred, though at other times the water may be in a dangerous condition. If a decision is based on chemical results alone, the presence of harmless organic material may be used to condemn a water, because the data do not distinguish between the organic matter which is vegetable and that which is animal in its origin. These troubles are experienced to a greater extent in the study of underground than in that of surface waters, first because the sources of pollution are obscure in their relation to the subterranean beds, and, second, because variations in the chemical constituents of a given spring or well under study are usually neither so large nor so diverse in character as the changes in the same figures for rivers or lakes. Chloride-bearing rocks or drift deposits sometimes give so high a chlorine content to waters in them that slight changes caused by the introduction of fecal matter are either inappreciable or can be attributed as well to natural sources as to dangerous contamination. Other constituents besides chlorine may change from similar causes without affording the analyst an opportunity to distinguish harmless from dangerous affluents.

Consequently every means for determining the flow and pollution foci of underground waters should be used. In studying the potability of a well or spring water it is important to know not only its chemical composition, but also its source, its rate of flow, the area tributary to it, the nature of the material through which it passes, and the contaminations to which it may be subjected before or during its underground journey. It is often a matter of much importance to know whether the flow is from a cesspool toward a neighboring well or in the opposite direction; it may be necessary to determine whether or not water

[a] Prepared in connection with the work of the division of hydroeconomics; M. O. Leighton, hydrographer in charge.

seeps from a contaminated brook into wells of a neighboring region; whether collecting galleries for public water supplies receive seepage from well-established sources of contamination; whether, in general, known foci of pollution are in immediate, though obscured, connection with sources of drinking water. Knowledge of this nature is especially important in the study of waters passing through formations full of seams or crevices, where there is opportunity for rapid circulation without much purification. The determination of the area draining to the underground supply affords data in regard to the quantity of available water as well as its quality. These and many other considerations make the study of conditions in the subterranean basin more important than laboratory examinations into the nature of the water itself.

FLOW INDICATORS.

MATERIALS.

For such hydrologic studies as have been indicated above much knowledge has been gained by introducing some foreign material into the aquifer under study and tracing its journey by samples from wells, springs, or temporary borings along its possible course.

A large number of substances have been proposed for this purpose. A few of those which have been more or less extensively employed are given in the following lists:

A. Materials dissolved in the water and recognized by chemical or physical tests: Sodium chloride, calcium chloride, ammonium chloride, potassium nitrate, lithium salts, and iron salts.

B. Materials dissolved in the water and recognized by their color: Potassium permanganate, fuchsine, Kongo red, methylene blue, and fluoresceïn.

C. Materials suspended in the water and recognized by microscopic examinations: Starch, flour, etc.

D. Cultures of bacteria suspended in the water and recognized in samples taken by their cultural characteristics: *Bacillus prodigiosus*, *B. subtilis*, *Saccharomyces cerevisiæ*, and *Mycoderma aceti*.

The principal requisites in the choice of a proper so-called flow indicator are—

1. It should descend to and traverse the aquifer in a manner and rate similar to the water itself.
2. It should be easily and quickly detectable in the samples of water taken.
3. It should not be decomposed nor its intensity greatly affected by the materials with which it comes in contact.

For different purposes and in different materials the selection of an indicator is varied. For determining the percentage of water entering one level from another the chlorides are especially fitted, because the amounts present can be accurately and rapidly determined. When, however, the volumes of water are extremely large and the subterranean journey is long the amount of salt or other chloride necessary to cause an estimable change in chlorine content is so great that the experiment is often impracticable. For the study of underground flows in alluvial deposits the use of ammonium chloride and sodium chloride as electrolytes appears to be especially good.[a] For investigating the purification power of strata through which water passes, cultures of beer yeast have proved very satisfactory.[b] For tracing the flow, however, of large or small underground streams through well-defined channels of size in rocks, especially calcareous formations, fluoresceïn has proved superior to anything else which has been tried. Its diffusion is rapid, it is applicable under many conditions, and it can be easily detected in enormous dilutions by means of the fluoroscope when it is not present in quantities large enough to be visible to the naked eye. On account of its many admirable qualifications, fluoresceïn has been extensively used by the city of Paris in the study of springs from which the major part

[a] Slichter, C. S., Rate of movement of underground waters: Water-Sup. and Irr. Paper U. S. Geol. Survey No. 140, 1905.

[b] Le Couppey de la Forest, M., L'étude des eaux de sources: Bull. Soc. sci. hist. et nat. de l'Yonne, pt. 2, 1902.

of the drinking water is taken. The records given on page 81 of experiments with fluoresceïn are taken from published reports of the Commission scientifique de perfectionnement de l'Observatoire municipal de Montsouris and from various articles published elsewhere by members of the laboratory staff.

HISTORY

Probably the first coloration experiments to establish the water origin of typhoid fever were made by Dr. Dionis des Carrières[a] in 1882, during a severe epidemic at Auxerre, a city about 85 miles southeast of Paris. Since that time the use of various dyes has been frequent for studying the underground movements of water. In 1887 fluoresceïn was used in the valley of the Avre.[b] M. Trillat in 1899 conducted elaborate investigations into the delicacy of certain dyes for flow indicators and the effect on them of passage through common soils.[c] The fluoroscope invented by him and perfected by M. Marboutin[d] is capable of detecting minute traces of fluoresceïn, and has made possible the extensive studies of ground flow now being conducted with that material. The work has assumed such proportions that the so-called sanitary analysis of water plays a rather subordinate rôle in the consideration of the springs. Under the direction of the Montsouris commission geologists, hydrologists, chemists, physicians, and other skilled professional men make a detailed study of the region in order to ascertain the purity of the water and the means for preventing avoidable pollution. Their work embraces a study of the water flow and of the geology of the formations, determination of the supply basin, inquiry into epidemics and hygienic conditions on the watershed, as well as the study of the water itself as regards chemical and bacteriological condition, discharge, temperature, etc. From the results of all these researches a definite decision concerning the availability of the supply and its chances of pollution can be made.

FLUORESCEÏN.

CHARACTER AND APPEARANCE.

Fluoresceïn (resorcin-phthalein, diresorcin phthalein, tetraoxyphthalophenone, uranin, Kruger's indicator) is a coal-tar product. It can be prepared by heating two molecular weights of resorcin with one molecular weight of phthalic anhydride, on an oil bath, between 190° and 200° C., until aqueous vapors are no longer evolved. The mass is then extracted with hot water and the residue powdered, dissolved in a solution of potassium hydrate, and reprecipitated with an acid. It is important to use pure materials in order to obtain a pure product, otherwise the final purification of the fluoresceïn is rendered extremely difficult. It occurs as crystalline powder or amorphous masses, varying in color from reddish yellow to dark brown. It is insoluble in water,[e] slightly soluble in cold, and more readily in hot alcohol, and easily soluble in ether, dilute acids, or alkaline solutions. The sodium or potassium salts of fluoresceïn are soluble in alkalies and in water. In the presence of alkalies its solution is red by transmitted light and bright green by reflected light—a phenomenon known as green fluorescence. Though fluoresceïn is not affected by free carbonic acid, its solution is rendered colorless by acetic and the mineral acids.[f]

The red color shown by transmitted light is not apparent in very dilute solution, but by the use of a long tube filled with the alkaline liquid the green appearance shown by

[a] Dionis des Carrières, Étiologie de l'épidémie typhoïde qui a éclaté à Auxerre en septembre 1882: Bull. et mém. Soc. méd. des hôpitaux de Paris, vol. 9, 2d ser., 1882, p. 277.

[b] Brard, Étude des pertes de l'Avre et de ses affluents: Comptes rendus Soc. ingénieurs civils de France, octobre 1899.

[c] Trillat, Sur l'emploi des matières colorantes pour la recherche de l'origine des sources et des eaux d'infiltration: Comptes rendus Acad. sci., vol. 128, 1899, p. 698.

[d] Marboutin, Nouvelle méthode d'étude des eaux de sources: Mém. Soc. ingénieurs civils de France, février 1901, vol. 131, p. 365; Sur la propagation des eaux souterraines: Bull. Soc. belge géol., etc., vol. 15, 1901, mém., p. 214.

[e] This statement of insolubility applies especially to chemically pure fluoresceïn sold ordinarily in the form of a yellow powder. The fluoresceïn commonly used in the coloration experiments has a reddish brown or slightly orange color and is completely and rapidly soluble in water.

[f] Cohn, Indicators and Test Papers, 2d ed., p. 75.

reflected light is apparent when extremely small quantities of fluoresceïn are used. For a flow indicator it is important to use fluoresceïn of good quality, as otherwise the coloration will not be visible in a solution sufficiently dilute. The commercial article varies greatly in intensity of fluorescence according to the purity of the materials from which it is manufactured and the care used in its preparation and storage. Nine different samples from the market examined by M. Marboutin[a] had greatly different fluorescent powers. With the fluoroscope their limits of visibility ranged from 1 part in 500,000,000 to 1 part in 10,000,000,000. The most practical test of the applicability of a given sample of fluoresceïn seems to be that when suspended in water it should show with the fluoroscope a perceptible fluorescence in a dilution of 1 part in 10,000,000,000. If weaker materials are used it is of course necessary to use larger quantities of them. Fluoresceïn costs from $2.25 to $12 a pound

THE FLUOROSCOPE.

The instrument known as the fluoroscope is used for detecting the presence of minute quantities of fluoresceïn in solution by observing the green fluorescence in a great depth of liquid against a dark background. As perfected by M. Marboutin,[a] chemist of the Montsouris laboratory, it consists of 12 tubes of pure-white glass of even bore, each 95 cm. long and about 15 mm. in diameter. The white tubing used for manufacturing certain kinds of burettes would answer the purpose very well. Each tube is closed at its lower extremity by a rubber stopper blackened with powdered plumbago. The box for carrying the apparatus is provided with a rack in which the tubes may be held side by side in a vertical position. When they are filled with the samples to be examined the presence of fluoresceïn is recognized by the appearance, projected on the black stopper, of a greenish reflection which is entirely different from the natural tint of the water itself, though sometimes confused with it by inexperienced observers. It is often convenient to use for comparison standard tubes containing quantities of fluoresceïn varying from 0 to 0.002 part per million. The use of a little ammonia to excite the fluoresceïn is suggested when the dye is present in small amount. This is of course impossible in magnesium-bearing waters on account of the white turbidity produced. The limit of visibility depends a great deal on the nature of the fluoresceïn used. It has been placed at 0.0001 part per million or 1 part in 10,000,000,000 of clear water. For practical demonstrations of its presence 0.0005 part per million is better. The limit of ordinary visibility with the unaided eye seems to be 0.025 part per million. Therefore a quantity of fluoresceïn may be used which is detectable with the fluorescope and still not visible to the naked eye.

By comparison with tubes of known content the amount of fluoresceïn in the samples may be estimated by the intensity of the green coloration. With this and other data the amount of seepage from one water-bearing stratum to another may be determined.[b]

APPLICATION OF FLUORESCEÏN.

Fluoresceïn can be poured down where there is expected to be a connection with the underground flow—in general at any point of higher elevation than the water level in the bed under study. Sink holes, cesspools, privy vaults, temporary borings, or the beds of degravelling streams are all desirable places to introduce the dye. A solution containing about 300 grams per liter is a convenient one for use. If it is poured down where there is no considerable flow of water toward the lower strata, such as in a dry boring or in a vault, enough water should be poured on it to wash it down. The quantity of fluoresceïn to be used varies with the distance traveled, the time of the journey, the size of the water sheet, and the nature of the material traversed. The amount generally employed is between one-half pound and 2 pounds, though experiments have been made with much larger weights. From tables given later (pp. 79–81), an idea may be formed of the amounts desirable to use. In general

[a] Marboutin, Contribution à l'étude des eaux souterraines: Comptes rendus Acad. sci., vo . 132, 1901, p. 365.
[b] See experiment at Auxerre, p. 82.

the quantity is 2 pounds of fluoresceïn per hour for a flow of about 31,700 gallons per minute from the bed. It is of course necessary to add enough to produce a detectable coloration in the water of the well or spring under examination. Having determined the flow of the latter, an approximation may be made of the amount of fluoresceïn necessary to insure the presence of between 0.02 and 0.0005 part per million in the effluent. Since, however, all of the water of the underground bed will probably not be delivered at the points of examination, it will be seen that with the distance traveled the amount of fluoresceïn should be increased.

METHOD OF TAKING SAMPLES.

A preliminary determination of the water level in the wells and springs in the region will eliminate those points round the spot at which the fluoresceïn is put down that are manifestly outside of the circulation zone. All other wells or springs should be marked for examination, whatever their apparent disconnection with the water sheet under study. The most economical manner of taking the samples is hourly by concentric circles successively removed from the point of putting in the color. An agent supplied with 12 bottles is stationed at each well or spring to be examined in the nearest circle. In general, samples taken hourly for twelve hours will mark the arrival and departure of the fluoresceïn. Sampling, however, should not cease at any point until the passage of the dye or its nonarrival is established. The first sample should be a blank taken at the instant when the fluoresceïn is put down, and each should be plainly marked with the name of the well or spring and the date and hour of sampling. After the color has passed one zone of wells, the agents can be moved to another circle. Their advance will, of course, depend on the rapidity with which the coloring matter progresses. The 12 samples representing the water for twelve hours are then examined in series as rapidly as possible.

EXAMINATION OF SAMPLES.

The 12 tubes of the fluoroscope are filled from the 12 bottles representing one well water. Care is taken to arrange them in chronological order. Then, by looking at the tubes along their axes, those showing fluorescence can be readily selected. It is often convenient for a beginner to use for comparison tubes containing dilute fluoresceïn solutions. With practice, however, the natural tint of the water will not be confused with traces of fluoresceïn. The examination should be made in broad daylight before a white wall. Special care must be taken to avoid a green background. By these tests the hours of arrival and of departure of the color at each point of examination are determined, and if desired the intensity of the fluoresceïn can be estimated.

ACTION OF FLUORESCEÏN.

Method of movement.—Generally fluoresceïn progresses more slowly than the water in which it is suspended; on account of the greater density of its solution it tends to accumulate in low places along the route traversed. M. le Couppey de la Forest[a] has noted that, when fluoresceïn is poured into a small stream which later widens out into a basin of still water, coloration is visible for a certain length of time in the stream below the basin; the coloration grows weaker, till finally not a trace can be found, though relatively large amounts of fluoresceïn-tinted water remain at the bottom of the basin; if finally the basin be agitated by the sudden influx of larger amounts of water, the more densely colored water will be washed out and the fluoresceïn will once more appear in the effluent. It may be conjectured that large subterranean caverns could effect a retention of fluoresceïn in a similar manner. The first appearance of the dye at the outlet might be unnoticed on account of its small amount, so that a later one caused by heavy inflows of water to the caverns would lead to a wrong conclusion regarding the rate of flow in the bed. Several instances of this character have been noted where one introduction of fluoresceïn has caused two or more distinct colored flows at springs in relation. (See p. 81.)

[a] Le Couppey de la Forest, M., Mode de propagation de la fluorescéine sous terre: Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 249; mém., p. 515.

The usual method of expressing the rate of flow of the fluoresceïn underground is in meters per hour or feet per minute, found by dividing the horizontal distance in a straight line from the point of entry to the point of appearance by the time which elapses between the hour of putting down the solution and its first appearance at the spring under consideration.

It has been mathematically demonstrated by M. de la Foresta[a] that the rate thus expressed is always less than the real rate of progress in the subterranean stream, from the fact that a certain length of time, generally indeterminate, is consumed by the solution in soaking into the lower stratum. If V = rate in feet per second, D = distance in feet, and T = time in seconds, then the rate is calculated thus:

$$V=\frac{D}{T}$$

Now T is evidently made up of two parts, or $T = t_1+t_2$, where t_1 =time consumed in infiltrating through the material separating the surface where the dye was put down from the bed in which the water circulates, and t_2 = real time during which the fluoresceïn is traversing the water stratum. Therefore the true rate V_1 is found thus:

$$V_1=\frac{D}{t_2}=\frac{D}{T-t_1}$$

And the difference between the true and the calculated rate is:

$$V_1-V=\frac{D}{T-t_1}-\frac{D}{T}=\frac{Dt_1}{Tt_2}$$

Whence it will be seen that the greater the time consumed by the preliminary infiltration the larger will be the error of the calculated rate; and the error will vary inversely with the permeability of the soil where the coloring matter is put down. If, furthermore, several wells are sampled at various distances from the entrance of the dye, it is usually found that the greater the distance traveled the greater is the calculated velocity for this reason:

$$V=\frac{D}{T}=\frac{D}{t_1+t_2}$$

But in the same experiment t_1 is constant, while t_2 varies in proportion with D. It is clear, therefore, that t_2 = KD where K is a constant indeterminate for the same experiment. So, substituting this value for t_2 in the above equation,

$$V=\frac{D}{t_1+KD}=\frac{1}{\frac{t_1}{D}+K}$$

In other words, the calculated rate varies directly with the distance traveled. In many cases this has been found to be true. (See p. 81.)

Decomposition of fluoresceïn.—In its underground passage certain substances exert a decomposing influence on fluoresceïn. Since its color is destroyed by acid solutions, it is evident that it can not be used in waters containing any free acids, except carbonic acid. A large amount of calcareous matter in solution, especially the carbonates, will decolorize the dye to some extent. M. Trillat[b] has reported the effect on fluoresceïn of contact with soils of widely different character. Fluoresceïn solution containing 1 part per million was passed through 30 cm. of soils containing large amounts of selected materials. The effluent was

[a] Op. cit., p. 251.
[b] Sur l'emploi des matières colorantes pour la recherche de l'origine des sources et des eaux d'infiltration: Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 301.

then examined for change in the intensity of the color. The result may be summarized thus:

Effect of certain soils on fluoresceïn.

Soil containing—	Percentage of organic matter.	Percentage of clay.	Change in fluoresceïn.
Lime	0	6.09	None.
Sand	4.56	0	Practically none.
Clay	7.96	79.20	Do.
Peat	49.07	35	Entirely decolorized.
Farm manure	....	....	None.

From this table it is seen that peaty soil will destroy the color, but that ammoniacal organic matter has practically no effect on it. Sandy soils and clay have almost no effect. By contact with water containing a large quantity of carbonate of calcium for twenty-four hours M. Trillat found that the intensity of the color was decreased about one-third.

EXPERIMENTS WITH FLUORESCEÏN.

Experiments in the Dhuis region.—The springs of Dhuis, an important part of the city water supply, are situated about 80 miles from Paris. The geologic strata in the region are a succession of permeable and impermeable beds—loam, limestone and millstone, (meulières de Brie), green clay, Champigny travertine, and *Pholodomya ludensis* marl, of which the travertine is the principal aquifer. This formation, 60 to 80 feet thick, is permeable and cut by fissures. Water circulates in it with great ease, often excavating large caverns by its action. It forms the bottom of all the valleys and ravines and a great part of their slopes. Since it is extremely permeable, it absorbes rain water and frequently engulfs the waters of brooks through sink holes (bétoires). From this bed the springs of Dhuis flow at a mean rate of about 3,670 gallons a minute. In 1901 experiments were made to determine the connection of these springs with possible sources of surface pollution. Fluoresceïn in varying amounts was poured into sink holes at different parts of the watershed and its progress noted by samples taken along its possible course. The results are as follows:

Experiments with fluoresceïn in Champigny travertine.[a]

No. of experiment.	Fluoresceïn used.	Distance traveled.	Difference in elevation.	Mean rate of slope.	Time elapsed.	Rate of flow.	Hardness.[b]
	Pounds.	*Feet.*	*Feet.*	*Per cent.*	*Hours.*	*Feet per minute.*	*Parts per million $CaCO_3$.*
1	1.1	0	....	....	....	....	....
1a	....	10,004	169	1.6	13	12.8	236
1b	....	10,332	166	1.6	14	12.3	218
1c	....	9,512	156	1.6	13	12.2	....
1d	....	9,676	159	1.6	13	12.4	....
2	.66	0	....	....	....	....	....
2a	....	4,756	162	3.4	7	11.3	762
2b	....	4,920	207	4.2	9	9.1	238
2c	....	6,396	226	3.5	12	8.9	234
2d	....	8,856	164	1.8	18	8.2	242
3	2.64	0	....	....	....	....	....
3a	....	17,384	126	.72	33	8.8	365

[a] Commission de Montsouris, Travaux des années 1900 et 1901, p. 208.
[b] The hardness of these waters was expressed in "degrés hydrotimétriques," 1° is equivalent to 10 mg. of calcium carbonate per liter. Post, Analyse chimique appliquée aux essais industriels, p. 9.

Experiments with fluoresceïn in Champigny travertine—Continued.

No. of experiment.	Fluoresceïn used.	Distance traveled.	Difference in elevation.	Mean rate of slope.	Time elapsed.	Rate of flow.	Hardness.
	Pounds.	*Feet.*	*Feet.*	*Per cent.*	*Hours.*	*Feet per minute.*	*Parts per million $CaCO_3$.*
3b	....	18,040	189	1.04	30	10	226
3c	....	18,532	188	1.01	30	10.3	218
3d	....	18,532	188	1.01	30	10.3	232
3e	....	18,532	188	1.01	32	9.6	218
4	1.76	0	....	....	....	....	....
4a	....	10,824	117	1.08	12	15	249
4b	....	10,824	114	1.05	12	15	710
5	.22	0	....	....	....	....	....
5a	....	1,312	42	3.2	4	5.5	214
5b	....	1,640	40	2.4	5	5.5	220
5c	....	1,640	40	2.4	5	5.5	210
5d	....	1,640	40	2.4	5	5.5	220
6	1.98	0	....	....	....	....	....
6a	....	8,856	....	....	18	8.2	....
6b	....	8,856	....	....	14	10.5	....

In column 1 the number of the experiment is given; the lettered numbers indicate points at which samples were taken; in experiment No. 1, for instance, samples were taken at four different places, numbered, respectively, 1a, 1b, 1c, 1d. Column 2 shows the amount of fluoresceïn used in each experiment. In column 3 is given the distance in a straight line between the point at which the fluoresceïn was put down and the point at which the sample was taken. In column 4 is shown the difference in elevation between the entering point of the fluoresceïn and the sampling point. Column 5 gives the average rate of slope of the water bed; it is found by dividing the difference in elevation by the distance between the points. In column 6 the time elapsed between the hour of putting down the fluoresceïn and its first appearance at each sampling point is given, while column 7 expresses the rate of flow of the fluoresceïn underground in each case. The total hardness of the water in column 8 is given to show that experiments with fluoresceïn may be conducted even when the amount of lime in the water is rather high.

One of the most striking features of these experiments is the distances that the fluoresceïn traveled. In experiment 3c, 3d, and 3e it went considerably over 3 miles and the time taken for the journey was over a day. Even for this great distance, however, the amount of fluoresceïn necessary was not excessive, being a little over 2.5 pounds. The rate of flow varied in different parts of the formation from 5.5 feet to 15 feet per minute, a figure which is influenced both by the slope of the water bed and the size of the apertures through which the water passes. In experiment 3 to 3e particular attention is called to the concordance of the results. In 3a, with a distance traveled of 17,384 feet and a total fall of 126 feet, the fluoresceïn progressed at the rate of 8.8 feet per minute. With an increase of the slope and some increase of distance traveled as shown in 3b to 3d there was, as would be expected, a corresponding increase in the rate of flow. In 3e, through some underground influence, there was a slight decrease in the rate of flow. Though these waters contained amounts of calcium, corresponding to a total hardness of 218 to 762 parts per million, yet no difficulty was experienced in making the experiments, even when the fluoresceïn was in contact with the calcareous rock from five to thirty hours.

These have been chosen as typical results in formations where there is free circulation of water through well-defined veins or seams, and not a slow seepage through beds of rock having small interstices. The principal points to be noted are:

1. Fuoresceïn is capable of traveling long distances.

2. Large amounts of calcium may be present without preventing the experiment.

3. Fluoresceïn is not destroyed by comparatively long contact with underground waters.

Experiments in the region of Yonne and Cure.—The results of only five experiments in the valleys of Yonne and Cure are noted in the following table, but they are noteworthy on account of the various conditions under which they were performed:

Experiments with fluoresceïn in the valleys of Yonne and Cure.[a]

No. of experiment.	Fluoresceïn used.	Distance traveled.	Difference in elevation.	Mean rate of slope.	Time elapsed.	Rate of flow.
	Pounds.	*Feet.*	*Feet.*	*Per cent.*	*Hours.*	*Feet per minute.*
1[a]	0.6	492			24	0.34
2[b]	6.6	0				
2a		15,580	228	1.4	100	2.5
2b		15,744	226	1.4	100	2.6
2c		15,744	226	1.4	101	2.6
2d		16,794	224	1.3	74	3.8
2e		19,680	230	1.1	72	4.6
3[c]	2.2	0				
3a		4,100		1.6	1.25	55
4[d]	4.4	0				
4a		19,680		1.5	34	9.6
4b		27,552		1.1	32	14
4c		38,048		1.1	42	15
		38,048		1.1	60	10
4d		37,884		1.1	40	16
		37,884		1.1	66	9.6
4e		38,212		1.1	43	14.8
		38,212		1.1	59	10.8
5[e]	4.4	0				
5a		42,984	322	.76	168	4.3
		42,984	322	.76	220	3.2
5b		43,558	328	.75	172	4.2
		43,558	328	.75	222	3.3

[a] Le Couppey de la Forest, M., Commission de Montsouris, Travaux de l'année 1902, pp. 38, 284.
[b] Idem, p. 259.
[c] Idem, p. 272.
[d] Idem, p. 286.
[e] Idem, p. 262.

In experiment 1 a small amount of fluoresceïn was put into a well about 160 feet deep bored in the compact limestones of the Rauracian. It required twenty-four hours for the coloring matter to progress a distance of about 500 feet. This experiment shows how slow the rate of flow is in limestone when that rock is compact and not cut up by large fissures. It also shows that fluoresceïn can permeate fairly solid rock even when it is not full of fissures.

Experiment 2 to 2e indicates the progress of the seepage from an irrigated tract of land about one-fourth mile from the hamlet of Souille. A brook flowing a little over 10 gallons a minute was diverted on a field of about 5 acres, where its waters were slowly but entirely absorbed into the soil. In the belief that this water reached springs of the region 6.6 pounds of fluoresceïn were poured into the brook; it appeared in these springs after intervals varying from seventy-two to one hundred and one hours. The rates of flow were low. Moreover, the springs farthest removed from the point where the fluoresceïn was put down had the highest rates of flow, though the mean slope toward them was less than in the nearer springs. This fact shows, as discussed on page 78, that the time consumed for the

infiltration of the fluorescein from the surface to the underground aquifer was considerable and concealed the true rate of flow in the subterranean channels of the lithographic limestones of the Sequanian and the Rauracian. Another interesting fact is that springs 2a, 2b, and 2c, namely, those nearest the irrigated field, were but slightly colored for twelve hours; on the other hand, springs 2d and 2e were colored for thirty-six hours with an intensity visible to the naked eye. The connection of springs 2d and 2e with the infiltration from the irrigated field would probably never have been suspected from a topographic survey of the region, because three dry valleys and considerable distances intervened.

On the left bank of Cure River a cavern called La Grotte des Goulettes is in direct communication with the river and engulfs a considerable portion of its water at all seasons of the year. At the time when experiment 3 to 3a was performed the cavern absorbed about 100 gallons a minute. After 2.2 pounds of fluorescein had been put into the water at the entrance to this cave it appeared in the water of a spring (3a) 4,100 feet distant, in one hour and fifteen minutes, after traveling at the high rate of 55 feet a minute. In this instance there was undoubtedly a well-defined subterranean channel of good size connecting La Grotte des Goulettes with the spring in question.

At Petit-Banny (experiment 4 to 4e), located in the valley of Druyes, 4.4 pounds of fluorescein were put on the porous bed. It traveled for the extraordinarily long distances of 19,680, 27,552, 38,048, 37,884, and 38,212 feet, through fissured limestone formations. It will be noted that in this experiment and in others where the distance traveled was less, with an increase of distance there is a corresponding increase in the rate of flow, showing that some time is taken for absorption into the underground channel. For springs 4c, 4d, and 4e two rates of flow are given, corresponding to two successive influxes of colored water, separated from each other by eighteen, fourteen, and fourteen hours, respectively. Probble reasons for two influxes, as previously discussed (p. 77), are either that the colored water arrived at the outlets by two different routes or that it became sedimented in some cavity and was then washed out by a later influx of water.

Experiment 5 to 5b gives the greatest distance for the underground journey of fluorescein noted in the reports at hand, namely, 43,558 feet in the experiment at Courson. Courson Brook is absorbed by progressive infiltration in the permeable beds of the Sequanian in a distance of about 650 feet along its bed. Four and four-tenths pounds of fluorescein were put into the stream. It was found at Crisenon (5a) and Grosse-Pierre (5b), over 8 miles away, after having traversed the fissured limestones of the Sequanian and the Rauracian at the rate of 4.3 and 4.2 feet a minute, respectively. At both of these springs a second flow occurred as noted. Even after such long journeys as these there is an apparent influence of the time taken for infiltration through the absorption bed.

Experiment at Auxerre.—An especially noteworthy experiment[a] was conducted at Auxerre to demonstrate the passage of polluted water from a ditch through alluvial deposits of sand and gravel into a collecting gallery from which the city supply was taken.

A collecting gallery about 300 feet long in the alluvium of the Yonne is situated 130 to 230 feet from the river. Its top is 2.8 feet and its water plane 4.3 feet below the surface. A polluted brook ran directly toward the collecting gallery until within 28 feet, then turned nearly at a right angle and paralleled it at about the same distance. Its water surface was from 1.2 to 3.5 feet above that of the gallery, from which 1,130,000 gallons of water were pumped daily. Two and two-tenths pounds of fluorescein were put into the brook 254 feet in a straight line from the collecting galleries, and samples were then taken of the water pumped from the galleries. Fluorescein was shown two and one-fourth hours after the dye was put into the brook, and an intense coloration was clearly visible to the naked eye in about ten hours, lasting thirteen hours. By examining samples from many sources throughout the city and estimating the amount of fluorescein present, it was found that the city water was colored for thirteen hours at an average of 1 part of fluorescein in 30,000,000. During that period about 600,000 gallons were pumped

[a] Le Couppey de la Forest, M., La fièvre typhoïde à Auxerre en 1902: Revue d'hygiène et de police sanitaire, vol. 24, pt. 6, 1902.

from the galleries, containing, therefore, 0.17 pound of fluoresceïn. Since 2.2 pounds were put into the brook and 0.17 pound reached the city water, it may be estimated that the ditch water reaches the galleries in the proportion of 2.2 to 0.17, or, to allow for some small error, about one-fifteenth of the brook water infiltrates to the town supply. Since the stream flowed at that time 950 gallons a minute, or about 1,370,000 gallons a day, while the gallery consumption was 1,130,000 gallons a day, it will be seen that about 8 per cent of the city supply was water from the polluted brook.

As previously stated, it took two and one-fourth hours for the fluoresceïn to reach the filter galleries. Assuming that the infiltration extended from the point at which the fluoresceïn was put down, the coloring matter would have progressed with a rate of 113 feet an hour through the alluvial deposits. If, on the contrary, the infiltration took place between the ditch and the gallery at the nearest point, it occurred at the rate of 12.4 feet per hour. Assuming a maximum filtration rate of 3,000,000 gallons per acre per day for an efficient sand filter, it may be inferred that this brook water reached the collecting galleries with practically no purification.

SUMMARY.

1. In determining the sanitary value of a well or spring it is more important to study the underground flow than to analyze the water itself.
2. Foreign substances put into the aquifer and traced from point to point are of great use in this study.
3. With the fluoroscope one part of fluoresceïn can be detected in 10 billion parts of water.
4. Fluoresceïn is a particularly valuable flow indicator for fissured or cavernized rocks.
5. It is also available in gravels, where it has been used with success.
6. It progresses at a slightly lower rate than the water in which it is suspended.
7. It is not decolorized by passage through sand, gravel, or manure; it is slightly decomposed by calcareous soils.
8. It is entirely decolorized by peaty formations and by free acids, except carbonic acid.
9. It has been used with much success for several years by the city of Paris.

PARTIAL BIBLIOGRAPHY.

ALBERT-LEVY. Rapport sur les expériences à la fluorescéine. Commission de Montsouris: travaux de 1899–1900, p. 225.

——— Vallées de la Vanne et de l'Yonne: Hydrologie souterraine. Communications entre les eaux superficielles, les eaux souterraines et les sources. Commission de Montsouris: travaux de 1899–1900, p. 291; travaux de 1900–1901, p. 249.

BRARD. Étude des pertes de l'Avre et de ses affluents. Comptes rendus Soc. ingénieurs civils de France octobre, 1899.

BRÉUILLE. Ville d'Auxerre: Adduction d'eaux des sources. Le Bourguignon, December 27, 1902.

COMMISSION SCIENTIFIQUE DE PERFECTIONNEMENT DE L'OBSERVATOIRE DE MONTSOURIS. Travaux sur les eaux d'alimentation et les eaux d'égouts de la ville de Paris. 1899 et seq.

COMMISSION DE MONTSOURIS. Programme des travaux de la commission technique pour l'étude des eaux potables captées pour l'alimentation de la ville de Paris. Travaux de 1899–1900, pp. 83–88.

CUONY. Emploi de la fluorescéine dans l'hydrographie. Bull. Soc. fribourg. sciences naturelles, C. R. 1901-1902, No. 10, p. 34.

DIENERT. Les sources de la craie. Revue générale des sciences, 1901, p. 1014.

——— Étude des sources de Fontaine-sous-Jouy. Commission de Montsouris: travaux de 1900-1901, p. 347.

——— Premier rapport sur le courant souterrain des Boscherons. Commission de Montsouris; travaux de 1900–1901, p. 387.

——— Études sur les sources de la ville de Paris captées dans la région de l'Avre. Commission de Montsouris: travaux de 1900–1901, p. 219; travaux de 1899–1900, p. 263.

——— Premier rapport sur les sources du Loing et du Lunain. Commission de Montsouris: travaux de 1900–1901, p. 159.

——— Quelques remarques sur les expériences faites avec la fluorescéine et le sel marin. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 438.

DIENERT ET GUILLERD. Sources du bassin de la Haute-Seine. Commission de Montsouris: travaux de 1900–1901, p. 565.

DIONIS DES CARRIÈRES. Étiologie de l'épidémie typhoïde qui a éclaté à Auxerre en septembre 1882. Bull. et mém. Soc. méd. des hôpitaux de Paris, vol. 9, 2e sér., 1882, p. 277.

FOREL. Le lac de l'Orbe souterraine. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 340.

FOURNIER. Lettre sur la fluorescéine. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 262.

FOURNIER ET MAGNIN. Essai sur la circulation des eaux souterraines dans les massifs calcaires du Jura. Bull. Soc. belge de géol., etc., vol. 17, 1903, mém., p. 523.

——— Sur la propagation des eaux souterraines. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 269.

——— Sur la vitesse d'écoulement des eaux souterraines. Comptes rendus Acad. sci., No. 14, April 6, 1903, p. 910. Also Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 444.

GOLLIEZ. Note sur les essais de coloration des eaux de l'écoulement souterrain des lacs de la vallée de Joux. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 336.

IMBEAUX. Note sur une expérience à la fluorescéine dans le plateau de Haye. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 353.

——— Lettre sur la fluorescéine. Bull. Soc. belge géol., etc., vol 17, 1903, proc.-verb , p. 267.

JANET. Note sur le captage et la protection des sources des eaux potables. Comptes rendus Acad. sci., vol. 131, 1900, p. 301.

——— Note sur l'emploi de la fluorescéine. Bull. Soc. belge géol , vol. 17, 1903, proc.-verb., p. 267.

——— Conférence de géologie appliquée sur le captage et la protection des sources d'eau potable. Bull. Soc. géol. France, 3e sér., vol. 27, 1899, p. 534.

——— Programme proposé pour les expériences de coloration à la fluorescéine. Commission de Montsouris: travaux de 1899-1900, p. 216.

——— Travaux de captage des sources des vallées du Loing et du Lunain. Livret-guide publié par le comité d'organisation du huitième congrès géologique international. Paris, 1900.

JÉRÔME. Exemple de la solution de menus problèmes d'hydrologie par le procédé de la coloration des eaux à l'aide de la fluorescéine. Bull. Soc. belge géol., etc., vol. 16, 1902, proc.-verb., p. 166.

KEMMA. Enquête sur les eaux de Paris. Bull. Soc. belge géol., etc., vol. 15, 1901, proc.-verb., p. 226.

——— Des différences de vitesse et de densité des eaux et sur les obstacles au melange. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 292.

LE COUPPEY DE LA FOREST. Lettre sur l'emploi de la fluorescéine. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 265.

——— Choix de l'emplacement des cimetières. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 112.

——— Étude des sources de vallées de l'Yonne et de la Cure; deuxième rapport. Commission de Montsouris: travaux de 1902, p. 151.

——— Étude du périmètre d'alimentation de la Dhuis. Commission de Montsouris: travaux de 1900 et 1901, p. 179; travaux de 1902, p. 151.

——— La fièvre typhoïde à Auxerre en 1902 Revue d'hygiène et de police sanitaire, vol. 24, p. 486.

——— Les expériences à la fluorescéine et les recherches hydrologiques effectuées pour la ville d'Auxerre. Bull. Soc. sci. hist. et nat. de l'Yonne, pt 1, 1903.

——— Méthode employée par la ville de Paris pour l'étude des eaux de sources. Bull. Soc. sci. hist. et nat. de l'Yonne, pt. 2, 1902, p. 27

——— Note sur une expérience à la fluorescéine effectuée à Cérisiers. Commission de Montsouris: travaux de 1902, p. 127.

——— Sources de la Dhuis: résumé du rapport présenté à la Commission de Montsouris.

——— Sur le mode de propagation de la fluorescéine sous terre. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 249; mém., p. 515.

LOHEST. Lettres sur la fluorescéine. Bull Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 265.

MARBOUTIN. Sur l'observation du trouble dans les eaux de sources. Bull. Soc. belge géol., etc., vol, 17, 1903, proc.-verb., p. 447.

——— Essai sur la propagation des eaux souterraines. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 273.

——— Contribution à l'étude des eaux souterraines. Comptes rendus Acad. sci., vol. 132, p. 365.

——— Études hydrologiques, mission du Val d'Orléans Commission de Montsouris; travaux de 1900-1901, p. 401.

——— Nouvelle méthode d'étude des eaux de sources. Mém. Soc. ingénieurs civils de France, vol. 131· 1901, p. 365.

——— Sur la propagation des eaux souterraines; nouvelle méthode d'emploi de la fluorescéine. Bull. Soc. belge géol., etc., vol. 15, 1901, mém., p. 214.

MARTEL. Sur l'application de la fluorescéine à l'hydrologie souterraine. Comptes rendus Acad. sci., vol. 137, 1903, p. 225. Also Bull Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 475.

——— Notes sur la vitesse et les retards de la fluorescéine. Bull. Soc. belge géol , etc., vol. 17, 1903, proc.-verb., pp. 265, 409.

——— Sur l'emploi de la fluorescéine en hydrologie. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb, p. 342.

——— Expériences complémentaires sur la fluorescéine. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 543.

PUTZEYS. Note sur la fluorescéine. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 263.

RABOZEE. Notes sur la fluorescéine. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., pp. 351, 541.

RABOZEE ET RAHIR. Résumé synthetique de la discussion relative à l'emploi de la fluorescéine pour l'étude de la vitesse des eaux courantes souterraines et à l'air libre. Bull. Soc. belge géol., etc., vol. 17, 1903, p. 620.

RAHIR. Une expérience au sujet du mode de propagation de la fluorescéine. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 398.

RUTOT. Nouvelles instructions à suivre pour l'étude des projets d'alimentations d'eau potable des communes de France. Bull. Soc. belge géol., etc., vol. 15, 1901, proc.-verb., p. 74.

SCHARDT. Notes concernant la vitesse de propagation de la fluorescéine. Bull. Soc. belge géol., etc., vol. 17, 1903. proc.-verb., p. 293.

THIERRY. Étude hydrologique et hygiénique sur le courant souterrain des Boscherons. Commission de Montsouris: travaux de 1902, p. 161.

TRILLAT. Sur l'emploi des matières colorantes pour la recherche de l'origine des sources et des eaux d'infiltration. Comptes rendus Acad. sci., vol. 128, 1899, p. 698.

——— Note sur la fluorescéine. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 261.

——— Essai sur l'emploi des matières colorantes pour la recherche des eaux d'infiltration. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 301. Also Annal. Inst. Pasteur, vol. 18, pp. 444–451.

VAN DEN BROECK. Les recherches de MM. Marboutin et Schloesing au sujet de l'étude des eaux potables. Bull. Soc. belge géol., etc., vol. 15, 1901, proc.-verb., p. 155.

——— La Lesse souterraine et sa traversée sous les deux boucles de Furfooz et Chaleux, demontrée par la fluorescéine. Bull Soc. belge de géol., etc., vol. 17, 1903, proc.-verb., p. 70; mém., p. 119.

——— L'indépendance de sources d'origines et de températures différentes infirmée par la fluorescéine. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., p. 403.

——— Notes sur la fluorescéine. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb., pp. 240, 355, 391.

VAN DEN BROECK ET RAHIR. Exhibition d'un tholomètre, nouvel appareil pratique destiné à mesurer le degré de transparence des eaux. Bull. Soc. belge géol., etc., vol. 17, 1903, proc.-verb.. p. 448.

——— Expériences sur la densité de la fluorescéine dissoute dans l'eau et sur la vitesse de propagation de cette matière colorante. Bull. Soc. belge géol., etc., vol. 17, proc.-verb., 1903, p. 531.

PECULIAR MINERAL WATERS FROM CRYSTALLINE ROCKS OF GEORGIA.

By MYRON L. FULLER.

INTRODUCTION.

In this paper are described a number of wells and springs in the Piedmont area of Georgia which, in view of the character of the rock in which they are sunk, afford mineral waters of remarkable character. The attention of the writer was called to the springs by Mr. S. W. McCallie, assistant State geologist of Georgia, who accompanied him on a visit to the locality and courteously furnished a number of analyses made by Dr. Edgar Everhart, of the local survey.

The waters, which, for supplies coming from crystalline rocks, are enormously high in chlorine and sulphates, are obtained from a number of wells and springs situated near the town of Austell, on the Southern Railway, in Cobb County, near the Douglas County line, 20 miles northwest of Atlanta and a little west of Sweetwater Creek, a tributary of Chattahoochee River. They are included in the Marietta quadrangle of the United States Geological Survey. One spring and three wells have been developed within a short distance of the town, their waters being placed on the market for medicinal purposes.

DESCRIPTION OF WELLS AND SPRINGS.

BORDEN LITHIA SPRING.

This spring, which is situated about a mile south of Austell and a similar distance northeast of Lithia Springs station, is stated to be the most important spring in Georgia from the standpoint of value of shipments. The water issues from a crevice in the bottom of a basin blasted out to a depth of several feet in the gneissoid granite, which here outcrops in strong ledges of almost unweathered rock. The basin is protected by a glass covering, and all surface seepage is carefully excluded. The yield, which is about 3 gallons a minute, is very constant, and the water has shown no noticeable change in composition since first discovered many years ago. In fact, the locality, because of the visits of deer to it for salt, has been known to the Cherokee Indians as the "deer-lick" from the time of their earliest traditions.

The composition of the water is shown in the table of analyses on page 88. The temperature is normal.

The principal spring at Austell was originally a few hundred feet west and across the strike from the Borden spring, but was ruined some years ago by an ingress of fresh water brought about by blasting in an effort to increase the flow.

Another salt spring, known as the Medlock spring, is located a short distance from the Medlock well (see p. 87), but is no longer used, and no analysis of its water was made. In composition, however, the water appears to be similar to those of neighboring wells and of the Borden Lithia Spring.

ARTESIAN LITHIA WELL.

This well, which is located near Sweetwater Creek, a little north of Austell, is 2 inches in diameter and is reported by some to be 900 feet deep, though others state that it is not over 750 feet. It appears to have been put down in search of anthracite coal, which someone imagined could be found in the granite of the region. The well penetrated for most of the way a gneissic rock, with which, it is said, some thin hornblendic layers were interbedded. The water, which is encountered in fissures at a number of different depths, rises nearly to the surface. It has a distinct saline taste, similar to that of the Borden Lithia Spring. An analysis is given in the table on page 88. This water, which is supplied at the rate of several gallons a minute without reference to season, is sold somewhat extensively as a mineral water.

An interesting point in connection with the occurrence of this saline water is that the Sulpho-Magnesia well, which was drilled to a depth of 750 feet only a short distance from the Artesian Lithia well, obtained only fresh water, although, so far as could be determined, the same succession of rocks was penetrated.

MEDLOCK WELL.

This well is located near the left bank of Sweetwater Creek, five-eighths of a mile northwest of Austell station and a few hundred yards southwest of the Sulpho-Magnesia well. It is 6 inches in diameter, 65 feet deep, and yields a supply of several gallons a minute from a fissure near the bottom of the well, the water rising to within a few feet of the surface. Except 5 feet of surface alluvium, the well is in a fine-grained gneiss. The composition of this water, which is highly saline, is shown in detail in the table on page 88.

J. H. LOUCH WELL.

This well, which was drilled in 1903, is located a few hundred feet from the Medlock well. It is 6 inches in diameter, 80 feet deep, and furnishes 1,500 gallons of water per day of twenty-four hours, the water rising to within 5 feet of the surface. The rock, as in the Medlock well, is a fine-grained gneiss. The water, which is very similar to the preceding, is put on the market in considerable amounts. The analysis is given in the table on page 88.

OTHER WELLS.

In addition to the saline wells already described and the Sulpho-Magnesia nonsaline well, there are four deep wells within the corporate limits of Austell. Two of these, near the railroad station, are 133 and 150 feet deep, respectively. Of the two others one is located at the Lithia Springs Hotel, and is 5½ inches in diameter and 150 feet deep. The other is the Brunk well, near Spring street, one-half mile south of the station. It is 6 inches in diameter and 110 feet deep.

The water in all four wells is low in mineral matter, soft, and free from salt, and is well suited for domestic or boiler purposes. So far as can be determined it comes from crevices similar to those from which the saline waters are obtained and from the same kind of rock. The locations are not such as to suggest any difference in geologic conditions.

COMPOSITION OF THE WATERS.

ANALYSES.

The composition of the waters is best shown by chemical analyses, a number of which made by Doctor Everhart, are given in the table below. The analyses in the first four columns are of the saline mineral waters, while that in the fifth column is of the nearly normal water from the Sulpho-Magnesia well, which is given for purposes of comparison.

Analyses of well and spring waters, Austell, Ga.

[Parts per million.]

	Saline waters.				Nonsaline waters.
	Bowden Lithia Spring.	Artesian Lithia well.	Medlock well.	Louch well.	Sulpho-Magnesia well.
Ionic statement.					
Iron (Fe)	1.05	0.21		0.45	0.61
Aluminum (Al)	1.33	.48		.40	.66
Manganese (Mn)	.20		Trace.	Trace.	Trace.
Calcium (Ca)	116.8	120.8	473.8	194.5	25.0
Magnesium (Mg)	9.2	12.9	53.8	26.9	3.6
Barium (Ba)	.18	.14		.22	Trace.
Lithium (Li)	5.6	17.0	14.5	8.8	2.5
Sodium (Na)	702.3	650.9	2,790.6	1,995.1	11.1
Potassium (K)	20.3	5.3	64.3	63.9	4.2
Silica (SiO_2)	32.6	24.3	26.2	11.6	18.0
Carbonate ion (CO_3)	80.3	113.6		35.0	51.5
Free carbon dioxide (CO_2)	70.9	80.0		70.1	82.7
Sulphate ion (SO_4)	181.4	178.1	769.8	581.2	3.6
Phosphate ion (PO_4)	27	.54	.15	Trace.	.47
Chlorine (Cl)	1,101.6	1,032.0	4,769.3	3,134.2	7.7
Bromine (Br)	20.7			2.8	
Arsenic (AS)	.10	Trace.			Trace.
Iron oxide and alumina ($Fe_2O_3+Al_2O_3$)			18.4		
Analyst's combinations.					
Manganese oxide (MnO)					Trace.
Iron carbonate ($FeCO_3$)	4.4	.90		1.22	2.6
Aluminum sulphate ($Al_2(SO_4)_3$)	10.9	3.9		1.36	5.5
Manganese carbonate ($MnCO_3$)	50		Trace.		
Calcium carbonate ($CaCO_3$)	156.6	189.3	40.7		62.5
Calcium sulphate ($CaSO_4$)	183.9	153.2	787.4	670.8	
Magnesium carbonate ($MgCO_3$)			267.6		12.6
Magnesium sulphate ($MgSO_4$)	45.9	64.2		133.3	
Barium sulphate ($BaSO_4$)	30			.38	
Lithium chloride ($LiCl_2$)	34.0	47.0	41.9	24.6	7.2
Sodium carbonate (Na_2CO_3)					24.8
Sodium sulphate (Na_2SO_4)	.30	21.1			1.2
Sodium phosphate (Na_2HPO_4)	.80	.80	.20	Trace.	.66
Sodium arsenite ($NaAsO_2$)	.40				Trace.
Sodium chloride (NaCl)	1785.0	1634.3	7093.8	5070.9	
Sodium bromide (NaBr)		4.0			
Potassium sulphate (K_2SO_4)					5.1
Potassium chloride (KCl)	.30		122.8	119.5	3.7
Potassium bromide (KBr)	30.8	16.2		4.2	Trace.
Total solids	2,286.6	2,159.2	9,058.0	6,096.9	131.4

Edgar Everhart, Geological Survey of Georgia, analyst.

COMPARISON WITH NORMAL WATERS.

A comparison of the analyses of the mineral waters near Austell with the normal waters of the region brings out some interesting features. Although the total solids in the mineral waters are from 16 to 70 times as great as in the normal water, the iron constituent is practically the same and in one case even less than in the ordinary water. The calcium, on the other hand, varies from 4 to 20 times, the magnesia from 3 to 15 times, the sodium from

60 to 250 times, and the potassium from about the same to 15 times as much as in the normal water. The silica, though varying from less than the amount in the unmineralized water to twice this amount, is essentially normal.

Not only does the absolute amount of the mineral ingredients vary greatly, but the proportion of the principal mineral substances also varies considerably, as shown in the following summary of the relative percentages of chlorine, sodium, magnesium, calcium, and potassium—five of the more important constituents of the waters.

Summary of percentage composition

	Average of four Austell mineral waters.	Sea water.	Normal Austell water.
Calcium (Ca)	5.2	1.2	48.6
Magnesium (Mg)	.6	3.5	6.9
Sodium (Na)	35.4	28.2	21.4
Potassium (K)	.9	1.0	8.2
Chlorine (Cl)	57.9	66.1	14.9
	100.0	100.0	100.0

In no instance does the amount of an ingredient in the Austell mineral waters occur in anything like the same proportion as in the normal water. The disagreement in the principal constituents—chlorine, sodium, and calcium—is especially marked, being as 57.9: 14.9, 35.4:21.4, and 5.2:48.6, respectively.

GEOLOGIC CONDITIONS.

LOCATION.

The Austell springs and wells are situated about 20 miles northwest of Atlanta, and are therefore located within the limits of the Piedmont Plateau. The distance from Austell to the borders of the Coastal Plain area to the southwest is about 90 miles, while the metamorphosed sedimentary Ocoee beds lie at a distance of about 10 miles to the northwest. The nearest point at which the later Paleozoic rocks occur is over 20 miles to the northwest.

The rocks in the vicinity of the spring and in the adjacent region in general are prevailingly of the gneissic type so common in the Piedmont area of this part of Georgia, although some more basic rocks occur as interbedded bands in the near vicinity. No unaltered sedimentary rocks occur nearer than the later Paleozoic border, 20 miles to the northwest.

CHARACTER OF ROCKS.

The rock from which the water issues is a light-gray granite with a well-marked gneissoid structure, which strikes with considerable uniformity in a north-south direction and is inclined at an angle of about 45° to the east. The granite appears to be interrupted by bands of a dark hornblende schist, a belt of which outcrops a short distance east of the wells and springs. The same or a similar rock was also encountered in the deeper wells.

A microscopic examination of the granite by Albert Johannsen showed it to consist essentially of quartz, microcline feldspar with a little albite and biotite-mica. The accessary minerals are titanite, apatite, and a little zircon. The composition was normal, no minerals being recognized which could have furnished the chlorine that is so abundant in the waters of the wells and springs.

The dark schist when examined under the microscope was found to consist mainly of hornblende, with quartz, augite, and a little plagioclase feldspar. As in the case of the granite, nothing was recognized which could have afforded the chlorine of the mineral waters.

JOINTING.

Owing to the mantle of decomposed rock constituting the surface throughout the Piedmont belt, joints are not so noticeable as in many regions. They are, however, to be seen in greater or less abundance in practically all the quarries throughout the belt. There are several different series which in a given district are generally fairly constant in direction. The best developed joints, according to T. L. Watson, have nearly due east-west or north-south directions, although in many instances the major series trend northwest and southeast.

SOURCES OF MINERALIZATION.

SURFACE ROCKS.

With the exception of the apatite in the gneissoid granite no mineral capable of yielding chlorine is present in the surface rocks of the region, and even the apatite is present only in exceedingly small amounts—no more than in all of the granites of the region—and is not sufficient to account for the wide variation of the Austell waters from the normal. The same is true of the hornblende schist, making it clear that the source of mineralization lies outside the rocks from which the springs issue and from which the wells draw their supplies.

DEEP-SEATED ROCKS.

The derivation of the mineral matter from the surface rock by meteoric waters being apparently ruled out because of the absence of minerals capable of furnishing to the water the dissolved substances, especially the chlorine, a deeper-seated origin suggests itself. To furnish chlorine in the amounts observed contact of the meteoric waters with some rock rich in sodalite or apatite must be postulated. This might be a sodalite-syenite or other syenite rich in sodalite, or a granite or similar rock high in apatite, and might be assumed to occur as a granitic or pegmatite intrusion reaching within the limit of circulating waters, but failing to reach the surface. An analysis made by N. Sahlborn of a pyroxene-apatite-syenite from Finland showed 14 per cent of apatite,[a] which if it was a chloro-apatite would be equivalent to 0.9 per cent of chlorine. In the sodalite-syenites the chlorine may run even higher, one sample of such rock from Greenland analyzed by N. V. Ussing showing 2.25 per cent chlorine.[b] Bearing in mind that the chloride minerals are in general much more soluble than the silicate minerals, one easily sees that rocks of the character indicated might well be the source of saline waters. No such rocks, however, have been reported in the part of Georgia under consideration, and if they occur they must be deep below the surface.

MAGMATIC WATERS.

It may be conceived that instead of forming a part of the circulating system of meteoric waters and deriving its mineral matter from some deep-seated rock with which it came into contact, the mineral water may represent what is known as magmatic water, or that excluded on cooling from some molten rock such as may have been intruded at some point below the surface near Austell. What has been said in regard to the absence of evidence as to the existence of chlorine-bearing rocks applies with equal force to intrusions capable of furnishing the magmatic waters. There is little evidence of disturbance of any kind in this region, either dynamic or igneous, in late geologic time, and if the water is of magmatic origin it probably represents an intrusion of considerable age.

IMPRISONED SEA WATERS.

As the general character of the Austell mineral water was suggestive of a sea water, figures showing the relative composition of the latter have been inserted in the summary. The resemblance of the two is very marked in the case of nearly every constituent.

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[a] Washington, H. S., Chemical analyses of igneous rocks: Prof. Paper U. S. Geol. Survey No. 14, 1903, p. 313.
[b] Op. cit., p. 303.

In the case of silica, however (not included in the summary), a difference is noted. The lowest amount in the Austell waters is 11.6 and the highest 32.6 parts per million. In sea water, however, ordinarily only from 2 to 5 parts per million are present. The difference, however, is probably not so great as would appear, as in the process of analyses the sea water was filtered before determination of the silica, while the spring waters were probably not filtered. Unfiltered sea water often gives results quite as high as that of the Austell springs.

SUMMARY.

Four possible explanations of the source of mineralization of the abnormal waters of the Austell springs have been suggested. These are: (1) That the mineral matter has been derived from the superficial country rock; (2) that it has come from deep-seated sodalite or apatite-bearing rocks; (3) that it represents water excluded from an igneous magma, and (4) that the water is in the main an imprisoned sea water conducted by joints and faults, etc., from the area of sedimentary rocks to the northwest.

The difficulty to be met by the first supposition is that the granite and schist in the vicinity of the springs and wells are normal and incapable of furnishing the observed chlorine. Except near the north-south line, along which the wells and springs described are located, none of the waters from the granite are saline.

The second and third views seem more probable, but the rarity of rocks high in sodalite or apatite, and the improbability that buried masses of such rocks or recent intrusions occur at the particular point under discussion, since they are not known elsewhere in the region, throw doubt on these explanations.

The origin from imprisoned sea water is favored by the percentage composition of the mineral waters, which is almost identical with that of sea water. The few minor points of difference are readily explained by the admixture of the normal fresh waters of the rock. The presence of such waters in close proximity to the fissures bearing the salt water is shown by the breaking in of fresh waters when blasting out the basin of the original spring, and by the fresh waters encountered by the four nonsaline wells described. The slightly high calcium in the mineral waters as compared with sea water could be produced by a very slight admixture of the normal waters of the locality.

The difficulty under the last hypothesis of origin lies in the absence of any source for the water. The crystalline rocks have not, as far as known, been covered by the sea since Archean time. The distance of the springs from sedimentary rocks, the metamorphism of the latter at the points nearest the springs, the rarity of saline waters even within the area of the sedimentary rocks, and our present lack of knowledge of any connection by faulting or jointing with these rocks are further difficulties in the way of the acceptance of such an origin. At the same time the lateral transition of water through joints or similar passages for long distances is not unknown. The writer has called attention to such a case on Fishers Island, New York,[a] the distance in that instance being at least 6 or 7 miles.

While the waters of the sedimentary area are in general not saline, such waters have been noted in the region. A well in Chickamauga Park, the waters of which were analyzed by Dr. Edgar Everhart, of the Geological Survey of Georgia, showed a total of nearly 60,000 parts of sodium chloride, or several times the amount in the Austell waters.

CONCLUSION.

It is the opinion of the writer that of the four sources of mineralization enumerated the first may be omitted from consideration. Of the remainder the probabilities of the second and third are primarily about equal and either may well be the true explanation. Owing, however, to the close agreement in percentage composition between the Austell mineral and ordinary sea water, the hypothesis of imprisoned sea water conducted from the sedimentary area by joints or faults to the point of emergence is not considered entirely impossible, notwithstanding the serious difficulties in the way of such transmission.

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[a] Geology of Fishers Island: Bull. Geol. Soc. America, vol. 16, 1905, p. 372.

PROBLEMS OF WATER CONTAMINATION.

By Isaiah Bowman.

INTRODUCTION.

There exists at the present time a considerable body of legal decisions relating to the disposition or the pollution of underground waters. These decisions are the outgrowth of controversies between well owners, and are based on real or supposed facts concerning the nature and movement of subterranean waters. In recent years our knowledge of the relation of water movement to rock structure and other factors has been greatly extended, and it is not surprising, therefore, that the decisions which would be affected by new acquisitions of knowledge should be inadequate when applied to cases at present under consideration. To secure justice in an action in tort decisions should be rendered not in accordance with precedent, but in accordance with the principles of justice sought to be established in preceding cases, the present better knowledge of the facts being taken into account.

This condition is illustrated in several sections of the country to-day, and it is desired here to present such cases in the hope that they may lead to worthy results both in the construction and care of wells of every variety and in the revision or promulgation of statutes intended to cover adequately the principles involved.

OIL AND GAS WELLS.

In the oil and gas regions of Pennsylvania, Indiana, Kansas, Texas, and other States considerable damage has been done by improperly allowing water to enter oil and gas sands to the exclusion of the oil and gas. The results have been so grievous that laws have been enacted in nearly every State where these substances are prospected looking toward their protection. By properly plugging abandoned holes wherever such water is known to enter, the driller has discharged his duties according to law by preventing contamination.

WATER WELLS.

DECAY OF CASINGS.

In the case of water wells, which, as a class, are of much wider distribution than either oil or gas wells, the same care is not exercised, though the results are sometimes as pernicious as in the preceding cases, if not of as great economic importance. In many States, as, for example, in Michigan, Wisconsin, and Washington, it has been made unlawful for a well owner to allow water from an artesian well to escape in needless amounts through the opening in the pipe at the surface. Often, however, it can be shown that even where such precautions are taken large amounts of water are being lost continually through defective casing.

When iron piping is put into the ground in the form of a sewer, it is not expected to last more than ten or fifteen years at the longest, but if it is put into the earth in the form of well casing there is usually no consideration of its longevity. It is tacitly assumed to last forever, while observations on casing withdrawn after having been in the earth both short and long periods show conclusively that it suffers deterioration and decay, and should be examined at short intervals for resulting defects.

No rule can be laid down as to the rate of decay, which will depend entirely on the conditions in individual cases. Casing withdrawn from wells fifteen to twenty years old has been found to be in reasonably good condition except at the joints, though the usual experience is that casing of this age is too badly decomposed to be withdrawn at all, except in sections, and even this is not always possible. On the other hand, if the waters which come into contact with the casing are heavily charged with minerals, their reaction on the pipe usually results in more rapid decay. At Dallas, Tex., the writer observed holes the size of a cent in casing withdrawn after having been in the earth but one year. The strong mineral waters

in one of the formations of that State, the Glen Rose, had so damaged the casing that it was little better than a sieve.

CONDITIONS OF CONTAMINATION.

Some general considerations at this time will make clearer the cases discussed in a later paragraph and may also throw light on future difficulties in problems of water supply or contamination.

Let us assume a condition which is so frequent throughout the country as to need no specific illustration—that of deep waters under much greater head than those lying nearer the surface, and further assume the no less common condition of defective casing—and we arrive at the result that large quantities of water must be lost before reaching the surface. Again, let us assume that the deeper water has been found to be unsatisfactory for domestic purposes because of dissolved minerals and that, while it rises in the well hole with artesian effect, it does not flow at the surface. If the well is now abandoned, the decay of the casing will in time allow this water access to higher water-bearing strata, and its entrance will mark the beginning of pollution of the upper waters. Before the condition is remedied, at the average speed with which municipal authorities move in matters of this sort, enough of the mineral substances will have entered and been deposited in the upper strata to make their redemption by natural filtration long and difficult.

PREVENTION OF CONTAMINATION.

Plugging.—The primary cause of the trouble must be dealt with, the polluting waters being shut out by plugging the bore hole above the point where such waters enter. This is done by driving down a wooden plug, which expands under the action of water and fits the well wall snugly. Earth is then thrown over the plug, which compacts, and by the time the plug has decayed is itself a preventive of further trouble. Various modifications may be introduced into specific cases which will complicate the problem, but a remedy can undoubtedly be found in each case.

Use of packers.—Where a hole is drilled in firm rock, throughout its entire length water may and often is derived from several strata—let us suppose three. If one of the sources proves unpalatable, it is necessary to separate the different waters and determine the source of the undesirable water. This may be done by temporarily shutting off two of the sources, thereby testing each one separately. If it is desired to test the lowest source, an expanding hollow rubber plug or packer is inserted above it, with a pipe connecting the top of the packer and the well head. Clutches, working automatically, keep the lower part of the packer in position, while the weight of the attached pipe presses down the upper part of the packer. By this means the middle part of the packer is forced to expand and to fit the walls of the well tightly. The lowest water is then drawn from the well through the attached pipe, being by the above means entirely separated from the waters above. By the proper adjustment of pipes, packers, and plugs each of the waters can be separated and examined in turn.

The remedy applied to a particular case will, of course, depend on the nature of the above determinations. If the lowest water is found to be the source of trouble, it may be plugged off, as already explained. Should the uppermost water be unpalatable, it may be shut off by applying a rubber packer below the undesirable water-bearing stratum and drawing water for use from the pipe connecting with the lower waters. In some cases it may be possible to keep a water of inferior quality in the rock by natural means. For instance, in drilling for an additional supply the driller may come to a sand in which the water is of lower head than the upper waters through which he has passed. In this event he may allow natural infiltration from the upper waters into the undesirable bed to take place. Unless the well is pumped too vigorously this will serve as a remedy, but the total yield of sweet water could in this case be utilized only by plugging the lowermost water.

NEED OF CAREFUL INVESTIGATIONS.

The only way by which municipal interests could be protected under any of the above conditions would be by making a thorough examination of the well hole and an exploration of

the amount and quality of each water contributing to the yield of the well. This would be very greatly facilitated by having at hand a log of the well—that is, a record of the character and extent of each of the formations through which the bore hole had been drilled. This has been recognized by one State at least. South Dakota requires this in the following statute:

It is hereby made the duty of the township board to embody in the contract for the sinking of said public artesian wells a proviso that the person sinking said wells shall make a record of the depth of each well and the formations entered or passed through in the construction of the same, and such provision is hereby made an essence of the contract, and a violation thereof shall be construed to be a violation of the contract. (Laws, 1891, chap. 80, sec. 35.)

It is interesting to note that this same State also requires that every person sinking an artesian well shall provide for such well a proper casing, in order to prevent the well from caving in, and to prevent the escape of the water when it is desirable that such water be confined. It is not clear, however, under the terms of the law, precisely what is meant by a proper casing, inasmuch as through the decay of the casing it may fulfill its function of confining strata or water for several months only, while again it may last for years.

It is not possible at this time to take up in greater detail the means by which the bore hole in various conditions may be explored. It is sufficient here to state that such exploration can in every case be accomplished along scientific lines, and that more and more this is actually being done.

To further suggest a way in which these ideas may be applied in a practical way to specific cases, let us take the instance of the partial failure of a given water supply as expressed by a loss of head. Heretofore this has generally been assumed to indicate that the limit of available waters had been passed and that in some way means should be adopted looking toward the maintenance of head. May it not be that in such cases the loss of head is partly or even entirely due to defective casing, which allows the water from lower sources to escape through the pipe and enter porous nonwater-bearing strata at a higher level, or to enter water-bearing strata the water of which is standing at a lower head? Several cases have come to the writer's notice in which the conditions were almost identical with the assumed case above, and it can not be too strongly emphasized here that some such result as the one above outlined must follow.

SPECIAL PROBLEMS OF CONTAMINATION.

Two specific illustrations of some of the above-mentioned conditions have been supplied to the writer by Mr. J. E. Bacon and are a result of experiments conducted by him looking toward the improvement of the water supply in the cities of Saginaw, Mich., and Dallas, Tex. Mr. Bacon's kind assistance in gathering these data and putting them at the disposal of the writer is hereby gratefully acknowledged.

Conditions at Saginaw, Mich.—At Saginaw, Mich., there are a large number of salt wells, many of which have been abandoned for one cause or another. In the abandoned wells the bore hole allows salt or brackish water to reach the surface under the influence of the natural head of the water, together with convection currents and diffusion. A part of the city supply had, previous to 1902, been drawn from a deep-well system consisting of about 20 bored wells having an internal diameter of 4 inches and a depth ranging from 89 to 230 feet. Most of these wells are in the bed rock and draw their supply from sources which have been contaminated by the infiltration of brine from the salt wells. Up to the time that Mr. Bacon began his investigations almost no attention had been paid at Saginaw to the protection of surface water from contamination of this kind. The seriousness of the situation may be appreciated from the fact that possible sources of ground-water supply at Saginaw are limited to the loose sands and gravels which overlie the rock and the top of the rock itself. Manifestly the only way in which this water can be conserved in its original purity is by plugging abandoned salt wells at a suitable distance below the surface and exercising great care in maintaining the casing in others intact. The condition has

been partly remedied by the above means and water obtained for municipal purposes from the glacial sands and gravels overlying the sandstone.

Conditions at Dallas, Tex.—The second case is the one illustrated by conditions at Dallas, Tex., where Mr. Bacon is at the present time (January, 1906) investigating the source and yield of potable water for city use. Water is yielded by four formations—the Woodbine, the Paluxy, the Glen Rose, and the Trinity—named in the order of their occurrence downward. While these are locally separated, the Glen Rose is really a part of the Trinity division. The lower Trinity sands have never been explored in the Dallas region, and their value as water producers is therefore unknown, but both the Paluxy and Woodbine formations contain sweet water. Most of the city wells derive water at the present time from the Woodbine, and it is the inadequacy of the supply from these sands which has led to the present investigations.

The peculiar conditions which are to be recognized here are those arising from the fact that one of the city wells penetrates the Glen Rose formation, and the water supplied from these sands is under a greater head than that from the overlying Paluxy. Moreover, the Glen Rose water is strongly mineral. Its exact composition has not been determined for this locality, but west of Austin the upper Glen Rose beds yield water containing strontium, magnesium, and sodium. Many residents of Dallas use the water for its real or supposed medicinal value.

This mineral water attacks the well casing so strongly that casing which had been in the well but one year exhibited breaks and checks in great number, and several of these were observed the size of a cent. The threads at the joints were completely decayed and unserviceable, so that when an attempt was made to pull the casing each length was lifted out as if it had no connection with the next lower length. Its value, therefore, as a tight casing was practically zero. Add to the conditions outlined the fact that the Glen Rose water is under greater head than the Paluxy and it is seen that gradually the Paluxy sands must become impregnated with the mineral substances in the Glen Rose water. While the water is used for medicinal purposes by a number of the citizens of Dallas, it is unpalatable as drinking water, and attempts to use it as such have proved unsuccessful. Its temperature is high and the contained salts give it a most unpleasant taste.

By inserting a packer with casing to the surface between the Glen Rose and Paluxy sands the two waters were separated, the mineral water with high temperature coming up inside the pipe and the Paluxy coming up between the pipe so inserted and the well casing. Differences in head and quality and temperature of water were at once noticeable, although the Paluxy waters were to some extent mineralized. The mineral content, however, steadily decreased as the experiment was continued.

RECOMMENDATIONS.

These two examples with the general discussion preceding are sufficient to show the vital character of the problems which they involve, and ought to lead to the following definite results:

1. An accurate log should be kept of every well drilled.
2. Every water-bearing formation should be carefully examined as to its thickness and the quality of the water yielded.
3. The head of each separate water should be accurately determined and its relation established with respect to other waters encountered.
4. The casing should be intact when the well is completed and should be kept so, its condition being determined from time to time by suitable experiments.
5. A change in the head or quality of the water should be interpreted only after the possible effects of defective casing are taken into account.
6. In those States in which the geologic conditions are known to favor contamination through the operation of one or the other of the causes noted herein, laws should be framed making the examination of the well casing and the determination of the exact relations of separate water-bearing strata the duty of each well owner or well driller.

INSTANCES OF IMPROVEMENT OF WATER IN WELLS.

By Myron L. Fuller.

INTRODUCTION.

Instances in which well waters which were pure at the time of drilling have later become mineralized and unfit for use are not uncommon, but cases in which waters originally high in mineral matter have later become fresh and pure are so seldom reported that they excite considerable comment.

Such an improvement in the quality of the water, however, is perfectly natural and is to be expected under certain definite conditions which are somewhat widespread. The water in soaking downward through the ground dissolves a certain amount of mineral matter from the materials with which it comes into contact. The longer the water remains in the ground the more mineralized it tends to become. Where underground circulation is active the water which has been in contact with the soluble materials of the rock is constantly being replaced by pure waters from the surface, and in such instances the ground waters are relatively low in dissolved solids. Where the circulation is slow, on the other hand, the water remains in contact with the surrounding mineral grains for long periods of time and often becomes highly mineralized. Such waters are especially likely to be found in beds which, while porous at the surface, pinch out or become impervious in their lower portions, thus tending to limit or prevent the free downward circulation of the water. Sometimes only a slight circulation is needed to improve the water, especially where it is in materials containing only small amounts of soluble matter. In such instances a single small well may sometimes effect a change in the composition of the water. A number of such instances were brought to light by work conducted under the direction of the writer near Wilmington, N. C., in 1905, and are described in the following paragraphs of this paper. For the facts regarding the wells the writer is indebted to Mr. L. W. Stephenson.

DESCRIPTION OF WELLS.

The wells here described may be taken as types of their class. They are located on the Atlantic coast at a point nearly due east of Wilmington, N. C., 10 miles or more from the city. One of them is on the mainland, near the shore of Greenville Sound, another on the Hammocks, just inside of the barrier separating the sound from the ocean, while the other two are on the barrier beach itself.

TARRYMORE HOTEL WELL.

The well of the Tarrymore Hotel, which is situated on the barrier near the inlet opposite the mouth of Wrightsville Creek, was drilled in 1905 by J. D. Lowry. It is 4½ inches in diameter at the top and 3½ inches at the bottom and has a depth of 195 feet. It passed through alternating beds of sand and thin layers of rock varying from soft to hard. Water was associated with the rock at 65 feet and at the botton of the well, the principal horizon being at the latter point. The water rises to within 4 feet of the surface, or about 5 feet above the level of the sea, the height varying somewhat with the tide. The well yields 25 gallons a minute when pumped.

When the well was drilled the water possessed a noticeable salty taste, but after it had been in use for some time the salt became less noticeable and eventally the water became entirely fresh.

LUMINA PARK WELL.

The Lumina Park well is located on the barrier a short distance south of the well just described. It was likewise drilled by J. D. Lowry in 1905, and is 3 inches in diameter and 198 feet deep. The elevation is somewhat lower than that of the Tarrymore well, and the well flows at high tide, although at low tide the water does not quite reach the surface. Twenty-five gallons a minute are obtained by pumping. This well passes through about the same succession of materials as the hotel well and obtains water from similar sand rocks.

When drilled this well also yielded water which was decidedly salty, but on continued use the salt taste gradually disappeared until at the present time the amount of chlorine is not much higher than in the ordinary fresh-water wells of the region.

HAMMOCKS WELL.

The Hammocks well, owned by the Consolidated Railway, Light, and Power Company of Wilmington, was drilled several years ago to a depth of 259 feet. The diameter is 8 inches at the top and 6 inches at the bottom. At 98 feet a cavity was encountered in hard shell rock and yielded a large supply of salty water. This was more or less effectively cased off and the well continued. Later a supply of fresh water began to appear through the larger casing surrounding the smaller one, but it is said that no water was encountered in the 6-inch portion of the well. The water may come from the cavity or along the lower casing from some lower horizon. The data were given from memory, and the cavity may in reality have been struck at a depth considerably greater than was reported, in which case it may possibly be correlated with the horizon in the Tarrymore Hotel and Lumina Park wells. At any rate fresh water is now obtained from some horizon which at the time of drilling yielded salt water or none at all.

QUARANTINE STATION WELL.

The well at the quarantine station is built on piles about half a mile from shore, near the mouth of Cape Fear River. It was drilled some years ago by Mr. De Witt, of Washington, D. C., and has a diameter of about 3 inches and a depth of 400 feet. Its elevation is several feet above high tide. The water level fluctuates with changes of tide, the water generally standing about 2 feet above tide level. It is pumped by steam at the rate of 4,500 gallons an hour.

When the pump is started after standing idle for some time, salt water, similar to that in the wells previously described, is obtained, but after a few minutes the salt rapidly decreases in amount and in less than twenty minutes it can no longer be detected by the taste.

CHANGE IN COMPOSITION.

NATURE OF CHANGE.

In the preceding paragraphs two instances of permanent change in the composition of the water from salt to fresh, under normal conditions of pumping or flow, are described. These changes were exhibited by the Tarrymore Hotel and Lumina Park wells. No analyses of the original waters from these wells were made, but in their saline content they were similar to the water yielded by the well at the quarantine station before pumping, a partial analysis of which is given herewith.

Field analysis of water from quarantine station well before pumping.

[L. W. Stephenson, analyst, 1905.]

	Parts per million.
Iron (Fe)	1.5
Calcium (Ca)	550
Carbonate radicle (CO_3)	195
Sulphate radicle (SO_4)	622
Chlorine (Cl)	8,374

The type of water yielded after the wells have been pumped or have flowed for some time is illustrated by the analysis of water from the C. W. Worth well. This well, which is located near the shore of Greenville Sound, just south of the mouth of Wrightsville Creek and about opposite the Tarrymore Hotel and Lumina Park wells, was drilled in 1904. It is 3 inches in diameter and 152 feet deep and obtained water from a bluish sandstone about 150 feet from the surface. The well is 8 or 9 feet above sea level and flows at the rate of 10 gallons a minute at a height of about 6 feet above the surface, the level varying somewhat with the tide. Like the other wells in the vicinity it was probably salty at the start. A partial analysis of the water now obtained is as follows:

Field analysis of water from C. W. Worth well.

[L. W. Stephenson, analyst, 1905.]

	Parts per million.
Iron (Fe)	1
Calcium (Ca)	200
Carbonate radicle (CO_3)	124
Sulphate radicle (SO_4)	None.
Chlorine (Cl)	85

The analysis of the water from the quarantine-station well before pumping may probably be taken as typical of the salty waters obtained from the wells in this region when drilled, while that of the water from the Worth well represents the maximum purity likely to be attained in these wells. Between the two there will be all gradations, one of which is represented by a second analysis of water from the quarantine-station well, made on a sample taken after pumping twenty minutes at the rate of 4,500 gallons an hour. This is as follows:

Field analysis of water from quarantine-station well after pumping.

[L. W. Stephenson, analyst, 1905.]

	Parts per million.
Iron (Fe)	1
Calcium (Ca)	209
Carbonate radicle (CO_3)	122
Sulphate radicle (SO_4)	36
Chlorine (Cl)	298

The decrease of mineral matter in the water of the quarantine-station well is gradual, and the water is unquestionably even lower in chlorine after pumping for thirty minutes than after twenty minutes.

It will be noted that the relative as well as the absolute amounts of the mineral ingredients of the fresh waters are entirely different from those of the saline waters. From over 8,000 parts per million at the start the amount of chlorine, for instance, may fall to less than 100, while the sulphates may decrease from 600 to nothing. At the same time the carbonates may actually increase, notwithstanding less than a tenth of the original total solids is present.

CAUSE OF CHANGE.

The change of the water from salt to fresh is believed to be due to the drawing in of fresh supplies from the surface after the exhaustion of the mineralized waters by pumping or by their natural removal through flowing wells. Whether the salinity was due to originally included sea water, to salt dissolved from the sediments, or to a penetration of sea water now going on can not be absolutely determined. The high percentage of calcium present, amounting to over 500 parts per million, indicates that sea water was not the only source of the salinity, since such water rarely carries over 5 parts per million.

The ease with which the salt water was removed and the composition of the water itself suggest that the derivation of the salinity from contemporaneous leakage of salt water is very improbable. Some of the salts may come from imprisoned sea water, but the general

character of the waters indicates that solution of matter from the deposits in which they occur or from beds with which they have been in contact is the predominating factor in determining their composition.

It is evident that the wells, although striking the water bed below the limit reached by the active circulation of the surface waters, were not beyond the limit of feeble circulation, for otherwise the mineral content of the water would have been much higher and more nearly that of the deep wells at Wilmington, in which the salinity approaches if it does not exceed that of ordinary sea waters.

APPLICATION OF PRINCIPLE.

The principle that originally inclosed sea or other highly mineralized waters may be removed by flowing or pumped wells is one which may prove to be of broad application to waters in the Coastal Plain and similar regions elsewhere. It means that a well should not necessarily be regarded as a failure if only salt water is obtained at the start. Instead of abandoning and plugging such a well it should be allowed to flow as freely as possible. No harm to underground supplies will in such instances be brought about by allowing free flow, while, on the other hand, as shown by the wells described, fresh water may be drawn into the water-bearing bed as the salt water is removed and a valuable well eventually secured. After the water has become fresh the flow or pumping, as the case may be, should be regulated and only enough water to meet actual needs taken. Otherwise the drain on the ground water may become so severe that the supply will be exhausted, as has often been the case.

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CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 160.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

Most of the above publications may be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they may be had at prices slightly above cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they may be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the fifty-eighth in Series O, the complete list of which follows (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

SERIES O, UNDERGROUND WATERS.

WS 4. A reconnaissance in southeastern Washington, by I. C. Russell. 1897. 96 pp., 7 pls. (Out of stock.)

WS 6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls. (Out of stock.)

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The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian-well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

QUALITY OF WATER

IN THE

UPPER OHIO RIVER BASIN AND AT ERIE, PA.

BY

SAMUEL JAMES LEWIS

WASHINGTON
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ILLUSTRATIONS.

QUALITY OF WATER IN THE UPPER OHIO RIVER BASIN AND AT ERIE, PA.

By Samuel James Lewis.

INTRODUCTION.

This paper discusses the quality of water on the most important tributaries of Ohio River in Pennsylvania, New York, West Virginia, and Maryland, and the nature of the water supply at Erie, Pa. The amount and character of the pollution is described and the results of drinking contaminated water as shown by typhoid statistics are indicated. The conditions on the tributaries of Ohio River in Ohio are discussed in Water-Supply and Irrigation Paper No. 79, United States Geological Survey, pages 129–187.

The water supplies and sewerage of small towns high up toward the head of a large drainage system do not in many cases receive the attention they should. Epidemics of a water-borne disease which affect large municipalities near the mouth of the river and therefore attract attention must necessarily have their origin in the pollution of the watershed above. It is evident, therefore, that adequate sanitation of the small towns and a water supply as carefully guarded as that of a large city would prevent disease at its very source and be far less expensive than the costly battles which are waged against epidemics in huge centers of population after disease has broken out.

Typhoid fever statistics for small towns in this section are seldom available and are more or less unreliable at best. The few figures given show the existence of virulent typhoid fever in most towns of the drainage areas in certain years, and as these towns drain into the streams the liability ofthe water to infection is evident.

The significance of typhoid fever death rates will be better understood from the statistics presented below, which have been collated from a number of cities having excellent water supplies.

Typhoid statistics of cities with good water supplies.

City and year.	Population.	Total deaths.	Typhoid deaths.	Total death rate per 1,000.	Typhoid death rate per 100,000.
Boston, Mass.:					
1900	560,892	11,678	143	20.82	25.6
1901	573,579	11,300	142	19.70	24.8
1902	584,553	10,983	139	18.79	23.8
1903	600,929	10,632	119	17.69	19.8
1904	614,522	10,757	135	17.54	22.0
Brockton, Mass.:					
1900	40,063	553	18	13.80	45.0
1901	41,606	523	6	10.17	14.4
1902	43,208	475	6	10.99	13.9
1903	44,873	495	5	11.03	11.1
1904	46,601	567	8	12.17	17.1

Typhoid statistics of cities with good water supplies—Continued.

City and year.	Population.	Total deaths.	Typhoid deaths.	Total death rate per 1,000	Typhoid death rate per 100,000.
Cambridge, Mass.:					
1900	91,886	1,547	15	16.83	16.3
1901	94,084	1,574	10	16.73	10.6
1902	96,334	1,454	17	15.09	17.6
1903	98,639	1,501	14	15.32	14.2
1904	100,998	1,444	23	14.30	22.8
Fall River, Mass.:					
1900	104,863	2,206	15	21.04	14.3
1901	108,311	2,143	21	19.78	19.4
1902	111,872	2,223	14	19.87	12.5
1903	115,549	2,290	27	19.82	23.4
1904	119,349	2,047	29	17.15	24.3
Jersey City, N. J.:					
1902	215,921	4,026	44	18.64	20.4
1903	219,462	4,130	36	18.82	16.4
Lawrence, Mass.:					
1900	62,559	1,250	11	19.98	17.6
1901	64,874	1,118	12	17.23	18.5
1902	67,275	1,163	11	17.29	16.3
1903	69,766	1,204	23	17.26	33.0
1904	72,348	1,141	11	15.77	15.2
Newark, N. J.:					
1902	258,176	4,831	50	18.71	19.4
1903	265,394	4,901	61	18.43	23.0
New York City.:					
1900	2,053,979	43,227	372	21.04	18.1
1901	2,095,686	43,304	412	20.66	19.7
1902	2,139,632	41,704	399	19.49	18.6
Yonkers, N. Y.:					
1900	47,931	810	2	16.89	10.4
1901	....	842	8	....	11.8
1902	....	865	5	....	....

OHIO RIVER BASIN ABOVE PITTSBURG, PA.

ALLEGHENY RIVER BASIN.

DESCRIPTION OF BASIN.

Allegheny River drains a quick-spilling area. The stream carries so much silt and other débris as the result of the rapid run-off that it is generally muddy. This, together with the sewage which it receives from numerous municipalities, makes it a poor source of domestic water supply. The towns at the headwaters have not generally used river water for public supply, but lower down, where pollution is greater, the unpurified water is supplied at many places. Springs are numerous and are much used, sometimes supplying towns as large as Bradford, which has 17,000 inhabitants. They fail, however, in dry seasons. Population is sparse, there being but 11 towns having over 5,000 people. Fig. 1 shows the location and approximate population of nearly all the towns within the drainage area.

The investigations prosecuted by the city of Pittsburg looking toward filtration of Allegheny River water showed conclusively that the nature of the watershed permits very little or no opportunity for self-purification by the processes which are usually more or

less effective in rivers. Furthermore, "such is the peculiar character of the river, such the character of the watershed, that infection introduced at much more remote points than Oil City may be actively dangerous to the health of Pittsburg." [a] If this be the case, what is to prevent infection of towns higher up on the river by the sewage and drainage of others at less distance above them than Oil City is from Pittsburg? It can not be urged as a palliative of conditions on Allegheny River that most of the towns are not sewered, for, owing to the nature of the topography, very heavy rain will drain contamination from every town on the watershed into the river. It has long been established that the increase in turbidity in such a stream has a direct relation to the increase in the quan-

FIG. 1.—Map of Allegheny River basin, showing approximate population of towns.

tity of bacteria. The work of Mr. Copeland, of the Pittsburg filtration commission,[b] shows conclusively that bacteria abound in the turbid waters of the Allegheny and that those bacteria which can come only from extensive sewage pollution are generally present. There are always a number of cases of typhoid fever within the drainage area of the Allegheny, and the topography of the country is such that sewage or drainage containing typhoid bacteria may be delivered to any point down the river within one or two days. It is obvious that infection anywhere on the watershed may readily reach any point below.

[a] Sedgwick, W. T., Report Filtration Commission, Pittsburg, p. 19.
[b] Ibid., p. 348.

ALLEGHENY RIVER BASIN ABOVE CONEWANGO CREEK.

Port Allegany, Pa. (population, 1,000).—Has a gravity supply from three small impounding reservoirs (capacity about 3,000,000 gallons) fed by Skinners Run and its tributaries. The daily consumption is about 100,000 gallons. This is a naturally safe surface supply, as the drainage area is all uninhabited forest land. In time, safety will require regular policing of the area. The town is not sewered.

There have been few borings for ground water. The best is the 75-foot well at the Sartwell House. The water from this well is much harder than that from the public supply, which contains almost no mineral impurities and would be excellent for any industrial purpose. Field assays of water from Port Allegany are given below. Typhoid-fever figures for Port Allegany are not sufficiently full to be worth quoting, as they merely establish the presence of typhoid fever in 1897, 1898, and 1899.

Smethport and Eldred, Pa.—Gravity supplies are in use at Smethport (on Potato Creek) and at Eldred (population of each, 1,000). Neither has a sewerage system. Typhoid-fever statistics are not available for Smethport, and those for Eldred are so meager that they are of little value.

Typhoid mortality at Eldred, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.	Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1894	....	2	....	1898	....	7	....
1895	....	24	1	1899	6	2	1
1897	....	7	2	1900	16	....	2

Field assays of water from Port Allegany, Eldred, and Smethport, Pa.

[Parts per million.]

Determination.	Port Allegany.		Eldred.	Smethport.
	Public supply.	75-foot well at Sartwell House.	Public supply.	Public supply.
Turbidity	0	0	0	0
Color	27	5	17	122
Iron (Fe)	0	(a)	(b)	Trace
Calcium (Ca)	Trace.	35	28	0
Total hardness (as $CaCO_3$)	20	130+	51	10
Alkalinity	19	84	44	13
Sulphates (SO_3)	0	(b)	Trace.	0
Chlorides (Cl)	5.6	11	5.6	4.2

a Very slight trace. b Slight trace.

The Eldred water is somewhat harder than most of the spring waters of this section. It would be excellent for any purpose, the incrusting solids being practically all carbonate of lime, which is not present in quantity sufficient to cause trouble in a boiler. The supplies from Eldred and Smethport would be well adapted to industries requiring especially pure water, like paper making. The high color of Smethport water points either to a marshy drainage or to a foul condition of the reservoir.

Olean, N. Y.—At one time the water supply of Olean was pumped directly from the river, which receives typhoid-fever infection from the sources mentioned above. The supply since 1889 has been obtained from driven wells, but connection has been made with the river for emergency. In 1896 and 1897 the wells were increased from a very few to 50, making the use of river water unnecessary until very recently. The population of Olean, according to the Twelfth Census, is 9,462.

Typhoid mortality at Olean, N. Y.

Year.	Total deaths.	Typhoid deaths.	Year.	Total deaths.	Typhoid deaths.
1891	162	2	1897	99	1
1892	154	1	1898	82	1
1893	162	7	1900	130	1
1894	79	4	1901	110	2
1896	120	4	1902	117	3

It is evident that even high up on the headwaters, where no large towns pour their sewage into the stream, the raw water is unhealthy for drinking. The improvement in condition after the enlargement of the ground-water system is noteworthy. The town is sewered, and the wastes from the large tanneries located there discharge directly into the stream. It is at this point that the first extensive pollution enters Allegheny River.

Bradford, Pa.—An unusually large spring furnishes water for Bradford (population, 17,000), on Tuneangwant Creek. The plant was purchased by the city from the constructing company some years ago. In 1904 the debt was completely paid, in spite of a 40 per cent reduction in the water rate in 1904 and a 28 per cent reduction in 1901. Three masonry reservoirs, with a capacity of 59,000,000 gallons, impound the waters of a number of small spring-fed streams. The drainage area of these streams is large; over 12,000 acres immediately adjacent to the streams are now owned by the city, which maintains a strict patrol of this area. It may be considered reasonably certain that no immediate pollution of the Bradford water supply is likely. The daily consumption is now about 1,800,000 gallons, or 96 gallons per capita. The use of meters is increasing steadily, and the management appears to be efficient. There is also an auxiliary system of artesian wells averaging 175 feet in depth, for use in time of drought, from which the supply seems practically inexhaustible. The town has both sanitary and storm sewers, draining into a little stream which ultimately finds its way into the Allegheny. It is clear that disease germs may be discharged into the Allegheny from Bradford.

Typhoid mortality at Bradford, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.	Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1892	....	....	5	1899	163	3	3
1897	157	....	4	1900	172	....	15
1898	....	....	4	1901	149	20	5

That Bradford, in spite of the excellent character of its supply, may occasionally have an outbreak of disease that will greatly increase the infection in its sewage is shown by the figures for 1900. The public supply is a very pure and soft water; the high color shown in the assay (on p. 14) is probably due to the nature of a portion of the drainage area.

Salamanca, N. Y.—Salamanca, (population, 5,000) derives a very excellent gravity supply from springs and has connections with the river for pumping in periods of drought. The village is practically free from typhoid fever, the annual saving probably representing much more than the rate of interest on the plant, besides the saving in lives.

Typhoid mortality at Salamanca, N. Y.

Year.	Total deaths.	Typhoid deaths.	Year.	Total deaths.	Typhoid deaths.
1891	55	2	1897	....	0
1892	....	0	1898	....	0
1893	....	0	1900	....	0
1894	....	0	1901	....	0
1895	34	1	1902	65	2

Where the annual deaths for a period of years are so few, it seems likely, in the absence of specific information to the contrary, that the occasional mortality from typhoid fever is due to other than water-borne infection.

Mount Jewett, Pa.—At Mount Jewett (population, 1,000), on the headwaters of Kinzua Creek, the public supply is piped from springs to two large tanks. There is no sewerage system. The only available figures showing typhoid-fever mortality for the village are those for 1902, when there were two deaths from typhoid fever. In the absence of definite knowledge as to the source of infection in these cases, no conclusion can be drawn as to the character of the water supply. There is no doubt, however, of the nature of Mount Jewett's contribution to the Allegheny drainage. The field assay below shows that the public supply is very similar to that of Bradford, pure and soft, and suitable for any industrial or boiler purposes.

Kane, Pa.—Kane (population 5,000) has a sewerage system discharging into a small branch of Kinzua Creek, which empties into the Allegheny just above Warren. This run also receives drainage from Clarendon, a village of about 1,500 population, which has no public water supply, and is said to have many cases of typhoid fever. The water supply of Kane is similar to that of Bradford. It is derived from a number of springs along Kinzua Creek, and is collected in two reservoirs on that stream and pumped to a standpipe, elevated over 300 feet above the intake, supplying about a half million gallons a day. There are four wells, averaging 100 feet in depth, at the waterworks, used in case of shortage. The entire watershed is protected under an agreement with the landowners along the stream quite up to its source, whereby no sources of pollution—such as cattle pens, privies, and slaughterhouses—and no dwellings are permitted within 200 feet of the stream. It is believed that the watershed is being kept reasonably clean. No figures showing typhoid mortality are available for Kane.

For use in boilers, Kinzua Creek water is stored in a large reservoir, making an auxiliary supply entirely separate from the public supply. This creek water is never used for drinking purposes. The field assays below show pure spring waters:

Field assays of public water supplies at Bradford, Mount Jewett, and Kane, Pa.

[Parts per million.]

Determination.	Bradford.	Mount Jewett.	Kane.
Turbidity	0	0	0
Color	61	22	5
Iron (Fe)	(*a*)	Trace.	0
Calcium (Ca)	0	0	0
Total hardness (as $CaCO_3$)	13	13	7
Alkalinity	12	12	17
Sulphates (SO_3)	0	0	0
Chlorides (Cl)	6.2	4.9	5

a Very slight trace.

CONEWANGO CREEK.

Jamestown, N. Y.—Conewango Creek, which enters Allegheny River at Warren, carries the sewage of Jamestown, N. Y. (population 25,000), where there are numerous industrial enterprises, all of which pour their wastes into the creek. In the most densely populated districts of the city the buildings are directly on and overhang the stream, so that dejecta from typhoid patients in these buildings enter the creek directly and are carried down Allegheny River. That there is some pollution of this kind at Jamestown is shown by the typhoid mortality figures herewith

Typhoid mortality at Jamestown, N. Y.

Year.	Total deaths.	Typhoid deaths.	Year.	Total deaths.	Typhoid deaths.
1891	240	10	1897	267	1
1892	299	10	1898	260	5
1893	395	10	1900	280	9
1894	306	7	1901	296	6
1896	224	3	1902	259	1

ALLEGHENY RIVER FROM CONEWANGO CREEK TO OIL CREEK.

Warren, Pa.—The public supply of Warren (population 10,000) was formerly derived entirely from Morrison Run, a small spring run about 4 miles from the city. In recent years drilled wells have been added to this source. During about eight months of the year (October to June) a gravity supply is furnished from a 3,500,000-gallon earth reservoir, situated on the run about 4 miles from the city. The average daily consumption is about 1,100,000 gallons. The dam is of rubble masonry, 26 feet 6 inches high; the bottom of the reservoir is of clean sand. The watershed is uninhabited, being almost virgin land. There is one farmhouse at the lower edge of the drainage area, which has been sewered out below the reservoir at the expense of the water company. Although there is no regular patrol, it would seem, from an inspection of the drainage area, that little danger of pollution exists. Five drilled wells, 58 to 66 feet deep, about 40 feet from low-water mark of Allegheny River, are pumped during the summer. The close proximity of the wells to the shore has caused considerable local anxiety as to the possibility of the river water seeping into the wells, as the town sewers into the river above and below. There is reason to suppose that no such seepage occurs. Analyses show that the waters from wells and river are radically different.

Field assays of well and river water at Warren, Pa.

[Parts per million.]

Determination.	Public supply, wells 58 to 66 feet deep.	State Hospital well, 66 feet deep.	Allegheny River.
Turbidity	0	0	[a] 40
Color	5	5	122
Iron (Fe)	([b])	0	.5
Calcium (Ca)	105	96	46
Total hardness (as $CaCO_3$)	....	130+	47
Alkalinity	134	96	54
Sulphates (SO_3)	([b])	0	([c])
Chlorides (Cl)	11	6.4	5.6

a Estimated. *b* Very slight trace. *c* Slight trace.

The ground waters are similar, and, like uncontaminated ground waters, are very clear and almost colorless. The river water shows the characteristic mineral content of the streams of this section—very similar to that from French Creek, Oil Creek, Clarion River, and Redbank Creek, subsequently noted. There are but 46 parts per million of total hardness. The color is very high, and is due partly to the marshy drainage of portions of the river bottom and partly to oil and acid wastes received at Riverside, which probably contribute the traces of sulphuric acid and iron. The well waters also are hard. There is a layer of blue clay about 17 feet thick between the river bed and the gravel stratum whence the wells draw their supply. The movements of underground waters are such that wells of this depth probably

draw upon water not seeping from the stream but flowing in the ground toward the river; in order that river water may enter the wells the natural flow of the underground water would have to be reversed. This is clearly shown in Professor Slichter's paper on The Motions of Underground Waters.[a] For industrial uses requiring small mineral content, such as steam making, the river water is best. The well waters will cause scale in boilers if not treated.

There is a well-developed sentiment at Warren with regard to the public health. The local board of health compiles each year a report of vital statistics, which shows that in 1904 there were 3 deaths from typhoid fever. An interesting study was made of the water supply of typhoid fever patients during this year. It was found that of the 27 cases reported 12 used water from private wells in whole or in part, 5 used city water, and the remainder used water derived from various sources. Much credit is due to the public-spirited citizens of this town for the attention they are giving to problems of sanitation and public health, as well as to the management of the public water supply. The only typhoid mortality figures at hand are obtained from the reports of the health officer, as follows:

Typhoid mortality at Warren, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1900	....	10	2
1901	....	18	2
1902	110	29	1
1903	112	20	1
1904	103	27	3

Excepting for the sudden rise in 1902, these figures compare favorably with typhoid mortality rates in most towns using pure water supplies. Again, the evidence is strong as to the kind of pollution going into the Allegheny.

Tidioute and Tionesta, Pa.—Between Warren and Oil City the population is scattered, there being along this stretch of the Allegheny but two villages, Tidioute and Tionesta, each of about 1,000 inhabitants. At these places the supply is obtained by gravity from spring-fed reservoirs in the adjoining hills, and there is no sewerage. As the villages drain directly into the river it is very likely that more or less infection enters the stream at these points at all times.

The two supplies are very different, though both are pure and excellent for any purpose. The Tionesta water is similar to the Bradford and Kane supplies. The Tidioute water contains carbonates, mainly those of either magnesium or the alkalies, with a little calcium. These are both greatly superior to the river water for any industrial uses. (See assay on p. 15.)

OIL CREEK.

Titusville, Pa.—At Oil City the Allegheny River receives the drainage from Oil Creek, on which the largest town is Titusville, with a population of about 8,000, with sanitary sewers discharging into Oil Creek. Much oil-well pollution also enters at this point. The public supply is entirely from ground water pumped from a system of 10 wells, 50 to 68 feet deep, located at the station on Oil Creek, about 1½ miles above town, and is so abundant (2,500,000 gallons daily) that very few meters are in use.

[a] Slichter, C. S., Water Supply and Irr. Paper No. 67, U. S. Geol. Survey, p. 29 et seq.

Typhoid mortality at Titusville, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.	Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1895	....	2	1	1899	91	18	1
1896	94	3	2	1900	90	20	4
1897	100	3	1	1901	84	10	1
1898	....	6	....	1902	....	10	....

This very excellent showing seems to testify to the purity of the water supply. The Oil Creek water (see assay on p. 18) is typical of this section and, although somewhat hard, is far superior to well water for use in boilers, as it contains few impurities besides a little carbonate of lime. The Oil Creek water, as previously noted, is very similar to that of Allegheny River. The high color is due in great part to the extensive oil-well pollution at this point. For industries requiring water with little mineral content, neither of these waters would be satisfactory.

Oil City, Pa.—Oil City (population 13,000) is situated at the junction of Allegheny River and Oil Creek. Up to four years ago the public water supply was pumped directly from Allegheny River without purification. It was not until the high typhoid-fever rate had become notable that a change was made in the source. Ten wells were drilled to a depth of about 50 feet at a point a mile below the town, and the water is piped to a large covered well 140 feet from the river bank. This well is walled with logs, spaced a quarter of an inch apart, in 3 feet of the loose gravel at the bottom; above this the sides are bricked up tightly. About 2,000,000 gallons a day are pumped from this protecting well, through a 24-inch main, 1½ miles to tanks and delivered by gravity to the consumers. In order to guard against a repetition of the scarcity of water experienced in the fall of 1904, four more wells are about to be drilled near those now in use. The weak point in the system is the fact that raw river water can be pumped at any time. In June, 1904, when water was scarce in this section, it was deemed necessary to use the river water, and official notices were accordingly printed in the newspapers early in June, warning all consumers of the temporary change. At the end of about ten days the well water was again used. No figures are available as to the effect of this change on the typhoid-fever rate, but data are at hand for the period in 1901, when the city well water was similarly contaminated with raw river water. Of 63 cases of typhoid fever occurring at that time, 39 originated in the city and 33 of the 39 used the polluted city water.

Typhoid mortality at Oil City, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.	Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1893	....	....	16	1898	127	36	4
1894	....	49	9	1899	172	73	6
1895	....	199	30	1900	163	98	7
1896	156	51	6	1901	201	63	6
1897	132	37	8	1902	118	16	3

The notable outbreaks in 1893 and 1895, when so many deaths from this cause occurred in the city, are examples of the ravages of this preventable disease. The residual typhoid cases are too numerous, remaining strikingly uniform until 1901, when the change was made from the polluted river water to the present ground supply. The decrease in the number of deaths is ample proof, if any were needed, that the raw river water contains the specific germ of typhoid.

Field assays of water from public supplies at Tidioute, Tionesta, Titusville, and Oil City, Pa., and from Oil Creek at Titusville, Pa.

[Part per million.]

Determination.	Tidioute.	Tionesta.	Titusville.	Oil City.	Oil Creek at Titusville.
Turbidity	0	0	0	0	[a] 50
Color	45	17	22	....	180
Iron (Fe)	Trace.	Trace.	([b])	Trace.	1.5
Calcium (Ca)	[a] 10	0	94	64	46
Total hardness (as $CaCO_3$)	20	18	130+	61	39
Alkalinity	61	21	100	77	36
Sulphates (SO_4)	....	0	[a] 5	Trace.	[a] 5
Chlorides (Cl)	5.6	4.8	10	13	5.6

[a] Estimated. [b] Slight trace.

The Oil City water is much softer than the Titusville supply. Neither, however, is as good as the pure spring waters of Tidioute and Tionesta.

FRENCH CREEK.

French Creek enters the Allegheny at Franklin, a little below Oil City. Four towns of considerable size drain into it—Corry, Union City, Cambridge Springs, and Meadville, Pa.

Corry, Pa.—Corry (population about 8,000) obtains water partly by gravity from a spring-fed reservoir and partly from deep wells. A number of circumstances have combined to give the reservoir water a poor reputation.

Typhoid mortality at Corry, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1892	....	....	3
1895	....	5	1
1899	93	2	1

These figures are so meager as to be useless except to show that typhoid fever was present in Corry in the years given. It may reasonably be conjectured, in the absence of information to the contrary, that there was at least as much of the disease in years for which figures are not available. It is not known how much sewage from Corry gets into French Creek. With more care in policing the watershed this stream should make a good supply; it is probable, however, that it will be entirely abandoned in favor of the ground water.

It would seem likely, from the absence of turbidity (see assay on p. 19), the extremely low color, and the high total hardness, that the well water is being used very largely, if not altogether, as the spring waters of this section are usually low in mineral content. This water is strikingly similar to that of the city supply at Warren and would give the same trouble in industrial uses (p. 15).

Union City, Pa.—Union City (population about 3,000), located about 10 miles below Corry, has a gravity supply from a spring-fed reservoir (see assay on p. 19). The old mains are largely wood, and are about to be replaced throughout with cast iron. A pumping station at the intersection of French Creek with the main street supplies French Creek water for fire purposes. It is so connected as to pump into the mains in times of scarcity. The town would do well either to build a larger reservoir for gravity supplies or to install a mechan-

ical filter to handle French Creek water. The town sewers into French Creek, and there is no pretense at sanitary inspection of its drainage area. With the pumping station in a position to pump dangerous water into the mains at all times, no confidence can be felt in the supply under present conditions. There is a striking similarity between the reservoir water and the creek water in all points, and it is especially significant that their chlorine content is practically the same.

No figures of typhoid-fever mortality are obtainable for this town except for 1894, when there were two deaths.

Cambridge Springs, Pa.—Fourteen miles below Union City is Cambridge Springs, a summer resort which has about 1,500 permanent inhabitants, and is annually visited by many people. The water of the public supply has been pumped from three drilled wells 66 to 100 feet deep, but as this gains color after standing a short while it has fallen into general disrepute, and its use has been practically abandoned, French Creek water being pumped instead. As Union City sewage pollutes this relatively small stream only a short distance above Cambridge, it is extremely inadvisable for this town to resort to such a supply. If typhoid-fever infection should be carried down the creek to Cambridge Springs and pumped into the city supply enough cases may occur in a single summer to destroy the reputation of the town as a summer resort. Interest in the public supply is now at a standstill. Most residents who can do so are drinking mineral water from the numerous wells and springs which have made the place well known. The present unsatisfactory condition of the supply should be speedily remedied either by drilling for a new ground-water source or by filtration of the French Creek water. Without such precaution a serious epidemic of typhoid fever will some day occur in Cambridge Springs. The town sewers into French Creek.

Field assays of public supplies of towns on French Creek.

[Parts per million.]

Determination.	Corry.	Union City.	French Creek at Union City.	Cambridge Springs.
Turbidity	0	0	0	0
Color	5	212	106	22
Iron (Fe)	(a)	(a)	0.5	0
Calcium (Ca)	92	Some.	57	41
Total hardness (as $CaCO_3$)	130+	75	61	61
Alkalinity	96	40	50	223
Sulphates (SO_3)	(b)	Trace.	0	c5
Chlorides (Cl)	5.6	5.8	5.6	42

a Very slight trace. b Slight trace. c Estimated.

The alkalinity of the Cambridge Springs supply is so much greater than the calcium present as to point to the probable presence of the carbonates of magnesium and the alkalies. This water is by no means bad for boiler uses, being strikingly similar in hardness to that of French Creek.

Meadville, Pa.—The danger of using French Creek water is greatly intensified at Meadville (population 10,000), about 15 miles farther down the stream. In addition to the farm drainage along its course, sewage from Cambridge Springs and Union City pollutes the creek continually, and during those seasons of the year when the turbidity is high it is utterly impossible to use the water without filtering it. Conditions became so very bad that in 1901 steps were taken to introduce a ground-water supply. It is of interest in this connection to quote from the Report of the Board of Water Commissioners of the City of Meadville for 1901:

On the one hand it was asserted that the waters of French Creek were polluted, nonpotable, and dangerous to human life. On the other hand there were those who contended that the waters of French Creek were pure and wholesome. Chemical analyses made by the most eminent water specialists in America demonstrated that the water of French Creek for domestic use could hardly be worse.

Typhoid mortality figures are as follows:

Typhoid mortality at Meadville, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.	Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1893	....	....	1	1898	93	8	2
1894	....	3	....	1899	172	24	12
1895	....	9	4	1900	169	27	5
1896	122	10	2	1901	174	52	8
1897	122	7	1	1902	175	48	11

The present supply was recommended by Messrs. Hering and Fuller after consideration of the alternative proposition of filtering French Creek. It is derived from sixteen 8-inch wells 45 to 60 feet deep, drilled in the water-bearing gravel underlying much of the valley of Cussewago Creek, a layer of clay between the surface soil and the gravel affording considerable protection against surface seepage. From these wells the city is pumping about 1,500,000 gallons a day. By putting down 9 additional wells 4,000,000 gallons may be made available. The pumping station and much of its machinery is new and is the latest step in the improvement that has marked Meadville's progress since the city acquired the water-supply plant. Under present conditions the supply must be considered as good as any of its kind in the country. If its use should beccome universal in the town typhoid fever would be practically wiped out in a year or two. The experience of the local board of health in 1904 was encouraging. There were 29 cases reported, 2 of them foreign, as against 87 for 1903 and 48 for 1902. It should be remembered that the new water supply was first used late in 1902, the city water previous to that time having been pumped from French Creek. Of the 27 cases properly chargeable against the town in 1904, 15 occurred in the third and fourth wards, where most of the wells whose water is used for domestic purposes are located. These wells draw from ground water contaminated by old buried cesspools.

Field assay and analyses of public supply at Meadville, Pa.

[Parts per million.]

Determination.	Field assay.	Analyses by George C. Whipple, New York.	
		Aug. 14, 1901.	Aug. 21, 1901.
Turbidity	0	0	0
Color	5	0	0
Iron (Fe)	0.5	0.10	0.15
Calcium (Ca)	92	....	....
Total hardness (as $CaCO_3$)	87.5	127	127
Alkalinity	115	120	119
Sulphates (SO_4)	[a] 10	....	3.0
Chlorides (Cl)	9	....	7.2
Albuminoid ammonia	....	.001	....
Free ammonia	....	.006	....
Nitrates	....	.000	....
Nitrites	....	.000	....

[a] Estimated.

This water requires a little treatment; for boiler uses the creek water is much better. The figures of albuminoid and free ammonia show that there is very little nitrogen in the water, and the absence of nitrates and nitrites shows that no organic matter had recently been added to it. For drinking purposes it is excellent.

ALLEGHENY RIVER BETWEEN FRENCH CREEK AND CLARION RIVER.

Franklin, Pa.—Conditions similar to those at Meadville have caused like difficulties at Franklin (population 7,000), on Allegheny River at the mouth of French Creek. The supply for some time was obtained by gravity from several springs, the water being impounded in a clean, well-constructed reservoir lined with paving brick, and of a capacity of 11,000,000 gallons. The watershed is unpopulated and is policed immediately about the reservoir. The amount of water impounded is, however, totally inadequate in dry seasons for the needs of the town. Nine wells have been drilled in sets of three, connected by a 12-inch line to the pumps, and so equipped with gate valves that any well or set of wells can be closed while the rest are being pumped. The results are fairly good, but it is likely that a stratum of ground water containing more storage than the one now drawn upon will have to be prospected for, as the present wells become low in dry times. During the last season's drought pumping from the wells had to be stopped entirely for a time, when a temporary plan of natural filtration was attempted. A trench about 6 feet across and 8 feet deep was dug at a right angle to the river bed, and the river water was pumped into it and allowed to percolate through the ground until it reached the stratum into which the wells were drilled. Not proving very successful in yield the plan was abandoned. This was perhaps fortunate, for it is not probable that this contaminated river water was purified by the process, as the wells average but 40 feet in depth. The idea is similar to that of Doctor Imbeaux, Ingénieur des Ponts et Chaussées, of Nancy, France, who built an "open canal through the gravel and conducts through it the river water parallel to the gallery and on the opposite side of it from the bank of the river; this has the effect of making both sides of the filter gallery equally effective. This method has been entirely successful."[a] A similar supply at Albion, N. Y., was condemned by the State engineer as unsafe. The city wells were located near a canal carrying polluted water, and in order to augment the yield from the wells, the water company dug trenches from the canal, which reached to the water-bearing gravel that supplied the wells. The State engineer held that the supply would be dangerously polluted by the infiltration of the canal water and ordered the trenches closed.[b]

Six additional wells, spaced farther apart than the present bores, would probably yield enough additional water to supply the town at all times.

Field assay of public supply at Franklin, Pa.

Determination.	Parts per million.	Determination.	Parts per million.
Turbidity	0	Total hardness (as $CaCO_3$)	75
Color	5	Alkalinity	90
Iron (Fe)	0	Sulphates (SO_3)	3
Calcium (Ca)	85	Chlorides (Cl)	13

This water is not so good for boiler uses as the creek or river water, nor is it suitable for industries requiring extremely pure water.

Emlenton, Pa.—Notwithstanding the pollution that comes in from Franklin and above it, Emlenton (population 1,000) is pumping raw Allegheny River water every day in the year as a water supply. An analysis of Allegheny River water at the Emlenton intake was made in 1902 for the State board of health and is relied upon by the people of the town as showing that the water is safe for drinking. This conclusion is not justified by the analysis, which is given below. The river is known to be grossly polluted by sewage containing pathogenic bacteria; the nitrate figure in the analysis shows considerable past pollution, and it remains

[a] Bechmann, M., Purification of water for domestic use: Trans. Am. Soc. Civil Eng., vol. 54, Pt. D (International Engineering Congress), p. 184.
[b] Eng. News, Oct., 1904.

to be proved that this past pollution is completely inocuous. Certainly no assurance of safety can legitimately be derived from one or two analyses. Emlenton sewers into Allegheny River.

Analysis of water from Allegheny River at Emlenton.[a]

Determination.	Parts per million.	Determination.	Parts per million.
Total solids	70	Free ammonia	0.02
Oxygen required	1.1	Albuminoid ammonia	.02
Nitrates	.16		

[a] Rept. Pennsylvania State Board of Health, 1902, p. 45.

CLARION RIVER.

A number of important towns are located along Clarion River, which empties into the Allegheny a few miles below Emlenton.

St. Marys, Pa.—St. Marys (population 4,000) is on Elk Creek, one of the headwater streams of Clarion River. It is supplied by a gravity system from reservoirs on Laurel and Silver runs, the reservoirs being filled by pumping. Frequent analyses of this water have been made at various times for the local water company, which takes considerable pride in keeping it in good condition. It is claimed that there is no typhoid fever here. The water is excellent for any purpose, either domestic or industrial. It does not seem likely that much drainage from this town gets into Allegheny River.

Johnsonburg, Pa.—Johnsonburg is a town of about the same size as St. Marys, situated directly on Clarion River, near its source. The water supply is pumped from a small reservoir about 1½ miles from the town. This reservoir is located on Powers Run, a mountain stream with a very uniform rate of flow, and of exceptional purity so far as mineral contents go. The daily consumption is about 75,000 gallons. No dwellings or privies are allowed along the banks of the stream, but this precaution is offset by the presence of pig yards, barns, and chicken yards. During every rain, and for some time after, the run is polluted by washings from these pens. Similar conditions exist lower down, at a small settlement containing about 12 families. During the summer of 1905 a contractor's camp was located directly upon the stream at the headwaters. Many cases of typhoid fever are reported in the town and the water is in bad repute, yet the meager figures obtainable as to typhoid mortality indicate a very fair water supply.

Typhoid mortality at Johnsonburg, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.	Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1895		4		1898	23	4	1
1896		2		1899	43	1	1
1897		1		1902	45	5	1

With intelligent inspection of this watershed Johnsonburg should have a water supply as good as any in the country. As it is the conditions may readily cause an epidemic of typhoid fever. The field assay (p. 24) shows the Powers Run water to be exceptionally pure and excellent for any industrial purpose. For domestic use it would be very good if not contaminated, as shown above.

Ridgway, Pa.—Clarion River above Ridgway (population 3,500) is polluted by the domestic sewage from Johnsonburg and by contamination from the paper mills there, as well as by the wastes from a very large tannery. The public supply of Ridgway is derived partly from a spring-fed reservoir on Gallagher Creek and partly from two wells, 92 and 94

feet deep, at the lower edge of the town, from which excellent water is pumped. These wells became infected a few years ago through a defective casing, which allowed leakage from adjoining sewers. Upon analysis the water was pronounced unsafe, and though the casing has since been replaced the supply is still somewhat under suspicion by the townspeople. The mineral analysis shows no unusual features for a water drawn from this depth. If used without treatment, it would give trouble in boilers. The Gallagher Creek supply becomes scanty in times of drought, so that the pumps at the wells are now furnishing nearly all the water to the reservoir, from which it is brought into the town by gravity. The figures available to show typhoid fever mortality are too few to serve as a basis for any conclusions as to the character of the water other than to prove that the town is not free from the disease and that its sewage therefore probably contains typhoid bacilli. The most serious outbreak was in 1895, when there were 36 cases of typhoid fever with one death.

In order to determine the effect of the industrial pollution mentioned, a sample was taken from Clarion River about a quarter of a mile below the tannery. It was so highly colored as to be unreadable by ordinary means, appearing black in the river, its shade being equivalent to an iron color of 4 parts per million. It is practically a slightly diluted tan liquor at this point. Except for the difference in color and alkalinity traced to the tanning wastes the two samples at Ridgway are strikingly alike. The influence of the sulphite wastes from the Johnsonburg paper mill is noticeable in the high sulphur trioxide figure.

Brockwayville, Pa.—Brockwayville (population 1,700) is located on Little Toby Creek, a tributary of Clarion River, entering a few miles below Ridgway. It has a spring-run gravity supply from a small reservoir on Whetstone Creek, 5 miles below the town. There is little interest in the matter in the village. The company officials state that the watershed is not populated in any way; but as there is no way of guarding against pollution of the reservoir, the supply can not be called wholly satisfactory. For manufacturing purposes the water is far superior to that of Toby Creek, which receives considerable mine drainage, as shown in the field assay (p. 24).

The public supply is typical of the spring waters of the section. The assay of water from Toby Creek shows the influence of mine drainage in the high sulphates and iron contents and in the nearly complete neutralization of the natural alkalinity of the stream by the acid drainage. This water is not suitable for domestic purposes and would cause much trouble in boilers from incrustation and corrosion. The iron is probably present as ferrous sulphate.

Clarion, Pa.—The largest town on Clarion River is Clarion (population about 2,500), 25 miles from the Allegheny. Its supply is obtained partly by gravity from a reservoir upon McLains Run, and it is said that Clarion River affords part of the supply by pumping and treatment with a mechanical filter. The sample analyzed seems too soft to have come out of the river. The McLains Run water should be a very satisfactory supply if the quantity remains sufficient during the dry season. The field assay shows the public supply to be a very fine soft water suitable for any purpose. The town sewers into Clarion River.

The figures available to show typhoid fever mortality at Clarion are few, but the large number of cases and high percentage of mortality show clearly enough that the polluted river water has been in use.

Typhoid mortality at Clarion, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1896	23	19	1
1898	16	16	2
1899	....	25	....
1900	30	26	1
1902	18	4	1

Field assay of public supplies in Clarion River basin.

[Parts per million.]

Determination.	St. Marys.	Johnsonburg.	Ridgway.	Brockwayville.	Clarion River.	Clarion.	Toby Creek.
Turbidity	0	0	0	0	0	0	[a] 5
Color	35	106	5	27	45	....	17
Iron (Fe)	0	([b])	3	([c])	0	0	4
Calcium (Ca)	0	0	119	0	0	113	84
Total hardness (as $CaCO_3$)	13	22	130+	13	....	130+	90
Alkalinity	9	12	133	14	18	63	7
Sulphates (SO_3)	0	0	[a] 28	0	0	41	104
Chlorides (Cl)	6	4.8	26	2.6	4.4	30	6.1

[a] Estimated. [b] Very slight trace. [c] Slight trace.

ALLEGHENY RIVER BETWEEN CLARION RIVER AND REDBANK CREEK.

Parker, Pa.—Parker (population about 1,000) is built in a line along the Allegheny River front and on top of the bluff overlooking the river. The waterworks station is at the extreme southern end of the town, the intake being well out in the middle of the stream. All sewage and drainage from the village finds its way into the stream immediately above the intake. Besides this there are two slaughterhouses located on Toms Run, which enters into the Allegheny a few hundred yards above the northern edge of the town. The sewage of Emlenton is emptied into Allegheny River a short distance farther upstream. The pumping station is a ramshackle building, filthy inside and out (see Pl. I, *A*). A privy in the building is located at the edge of the shore, so that every rain washes pollution into the stream right at the intake. This is one of the grossest cases of ignorance and uncleanliness in water supply that has been noted in the course of this investigation. The pumping station is so located as to supply water contaminated not only with all the pollution from above, but also with that at the very doors of the town. Reliable figures as to typhoid fever here would be extremely valuable. During the few hours spent in the town 6 cases were located. This plant was installed about thirty years ago and has been in continuous operation since. It is said that the cleaning which the tank has just received was the first that it has had in many years. The first cost of the pumping plant could not have been more than the few hundred dollars necessary to purchase the tank and the small gas-engine which is doing the pumping. The plant should be replaced by a ground-water system similar to those of Warren and Oil City.

Field assays of water from Allegheny River at Parker, Pa.

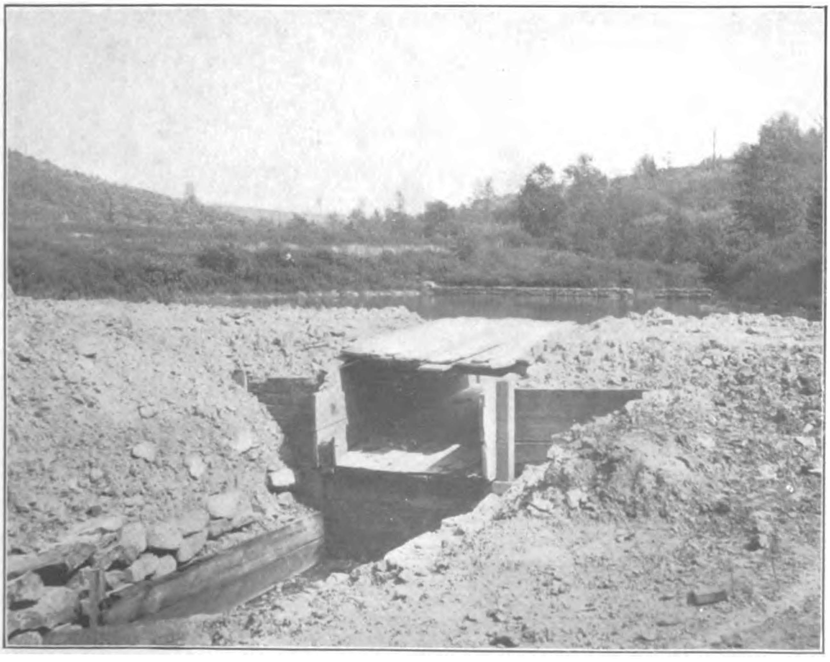
Determination.	Parts per million.	Determination.	Parts per million.
Turbidity	[a] 5	Total hardness (as $CaCO_3$)	59
Color	7	Alkalinity	54
Iron (Fe)	2	Sulphates (SO_3)	[a] 5
Calcium (Ca)	59	Chlorides (Cl)	26

[a] Estimated.

The field assay of water from the river at Warren (see p. 15) showed 5.6 parts per million of chlorine at Warren, agreeing very closely with the 5.0 parts per million shown by the analysis at Emlenton, several miles above Parker. The very high rise in the chlorine at Parker is probably traceable to the salt used at the slaughterhouses at Toms Run and seems to point to direct pollution of the river above the intake from this source.

A. PUMPING STATION AT PARKER, PA.

Showing condition of building.



B. DAM AND RESERVOIR OF PUBLIC SUPPLY AT REYNOLDSVILLE, PA.

Showing flimsy construction.

REDBANK CREEK.

Redbank Creek, an important tributary of the Allegheny, enters the main stream at Redbank Furnace, about 15 miles below Parker. There are four towns of consequence on this tributary drainage area—Dubois, Reynoldsville, Brookville, and New Bethlehem.

Dubois, Pa.—Dubois (population 10,000) has a gravity supply from large reservoirs that impound the waters of Anderson and Wolf creeks. The Anderson Creek reservoir, 9 miles from town, has a capacity of 150,000,000 gallons, the daily consumption being 1,000,000 gallons. There was no shortage here in the summer of 1904 at the time when drought was felt throughout this section. The supply is allowed to flow "wild" through the mains into town, and the excess goes on to Wolf Creek reservoir, where it is collected for storage, to be pumped back in time of need. The watershed is cleared of habitation, is partly owned by the company, and is patrolled at all times by a paid constable. The reservoirs are cleaned twice a year, and it is claimed that all cases of typhoid fever are traceable to the use of private wells, nearly all of which have been abandoned. Judgment as to the water supply of Dubois can hardly be definite in view of the meager figures at hand as to typhoid fever. The water seems to be good.

Typhoid mortality at Dubois, Pa.

Year.	Total deaths.	Typhoid deaths.
1897	66	2
1900	138	3
1901	151	3

This water shows (see assay on p. 20) a bright red coloration after being heated to boiling point. This is probably due to the presence of iron as iron carbonate, which loses carbon dioxide on heating, leaving the red ferrous oxide as a precipitate in the water, $FeCO_3 - CO_2 = FeO$, which combines with oxygen in the water to form Fe_2O_3 as a red precipitate.

Before the present large reservoir was in service, three deep wells, now plugged, were sunk, in search of an additional supply. Neither quantity nor quality was satisfactory. The town sewers into Sandy Creek, a tributary of Redbank Creek.

Reynoldsville, Pa.—Ten miles below Dubois is the town of Reynoldsville (population about 5,000). It has a surface supply from two small reservoirs, one of which is held in reserve. The one actually in use covers about three-fourths of an acre and does not appear to be in good condition, being apparently foul on the bottom and sides. The primitive character of the works is shown in Pl. I, *B*. The earth dam is but a temporary structure and the spillway a rough boxing of planks. The pool impounds the little run on whose course it is built, and receives the flow of two springs besides. There is evidently but a few days storage, and the supply is inadequate. In the fall of 1904 the prevalent scarcity led to the drilling of two wells right at the pumping station, the water from which is said to be a little harder than the spring water. These are not in operation at the present time, being held in reserve.

Typhoid mortality at Reynoldsville, Pa.

Year.	Total deaths.	Typhoid deaths
1899	38	2
1902	44	1

With the reservoir in its present condition, the water supply is certainly not beyond suspicion. The land around this reservoir is all in cultivation, and there is no policing of the drainage area. An assay of the water is given on page 26.

Brookville, Pa.—Brookville (population 2,400) is a rapidly growing lumber town, located between the confluence of the North Fork and Sandy Creek. The town supply is pumped directly from the North Fork, without purification, into three 3,000-barrel steel tanks, whence a daily consumption of about 290,000 gallons flows by gravity into the mains, so that there is little or no opportunity for sedimentation. A field assay is given below. Pl. II, *A*, shows the pumping station and conditions at the intake, which is in the mill pond about 30 feet out from the bank. The pond is a stagnant pool whose surface is littered with scum, chips, logs, oil, and lumber-yard refuse, and at the time the sample was taken presented a most uninviting appearance. Judging by the high-water mark here conditions must be much worse when the spring freshets sweep débris from the whole course of the stream into the pond. A mile upstream, at another sawmill, are located the houses of a few families right on the stream. The water has a high color, doubtless due to the rubbish mentioned above.

The few statistics available as to typhoid fever show the constant presence of the disease, sometimes in high rates.

Typhoid mortality at Brookville, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.	Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1895	....	3	....	1899	36	6	2
1896	34	13	2	1900	....	3	....
1897	....	1	....	1901	28	3	2
1898	24	11	2	1902	....	8	....

Sandy Creek, although most offensively polluted at Reynoldsville by the tannery, presents a perfectly clear appearance at this point.

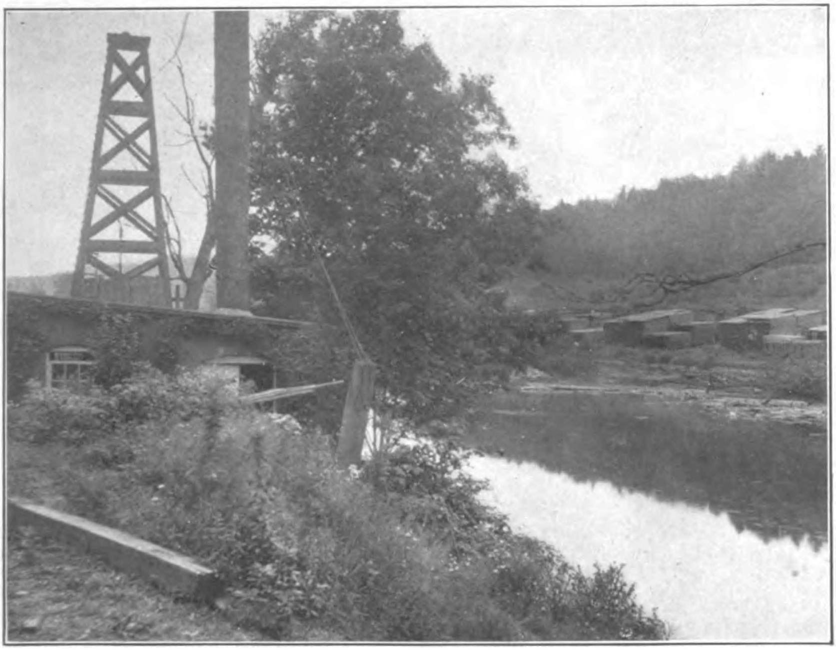
New Bethlehem, Pa.—Near the mouth of Redbank Creek is New Bethlehem, a town of about 2,000 population. Here there is a very good, well-equipped water-supply plant. The water, which is rather hard and of the limestone type, is pumped from Redbank Creek into a settling basin holding approximately 180,000 gallons, whence a small gas pump raises it into a small mechanical filter. Washout gates on the distributing mains are used for flushing out any deposited matter. The reservoir and filters are covered, being brick and cement structures, and intelligent supervision is exercised over the entire plant. The supply seems to be good and to give satisfaction. The machinery is all modern. The low alkalinity of this water in the presence of so much calcium carbonate probably results from the acidity of chemicals added in the filtration process. This supply should cause no trouble in boilers and should be available for many other industrial uses.

Field assays of public supplies from towns in Redbank Creek basin.

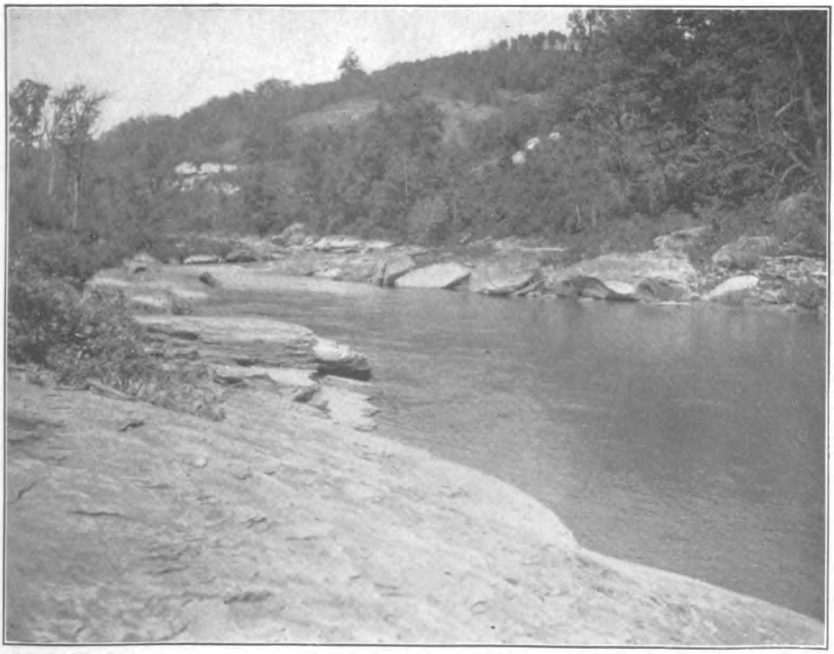
[Parts per million.]

Determination.	Dubois.	Reynoldsville.	Brookville.	New Bethlehem.
Turbidity	0	0	0	0
Color	96	35	90	27
Iron (Fe)	1	(a)	Trace.	(b)
Calcium (Ca)	0	Some.	0	33
Total hardness (as $CaCO_3$)	15	30	20	39
Alkalinity	19	24	21	12
Sulphates (SO_3)	0	Trace.	0	c 20
Chlorides (Cl)	2.2	3.9	3.9	8

a Very slight trace. b Slight trace. c Estimated.



A. INTAKE OF PUBLIC SUPPLY AT BROOKVILLE, PA.



B. TYGART RIVER AT TYGART JUNCTION, W. VA.

Showing nature of stream bed.

MAHONING CREEK.

Punxsutawney, Pa.—Mahoning Creek flows through a sparsely settled country; the only important town on it is Punxsutawney, with a population of 4,375 in 1900. This obtains a gravity supply from Clover Run, whose water is used without purification. The Punxsutawney water is of the usual spring type, the great difficulty with it being its occasional turbidity. A slight amount of patrolling would make the supply quite safe. The only typhoid-fever data available for Punxsutawney are for 1902, when there were two deaths from this cause.

Field assay of water from Punxsutawney, Pa.

Determination.	Parts per million.	Determination.	Parts per million.
Turbidity	[a] 15	Total hardness (as $CaCO_3$)	15
Color	90	Alkalinity	21
Iron (Fe)	0.5	Sulphates (SO_3)	0
Calcium (Ca)	0	Chlorides (Cl)	5.6

[a] Estimated.

ALLEGHENY RIVER BETWEEN REDBANK CREEK AND KISKIMINITAS RIVER.

Kittanning, Pa.—Kittanning (population about 4,000) pumps from Allegheny River and is now installing a filtration plant, after passing through a painful experience with typhoid fever. The disease may be said to have been continuously epidemic here for years, as shown by the following figures, the number of deaths being among the highest in the country.

Typhoid mortality at Kittanning, Pa.[a]

Year.	Deaths per 100,000.	Year.	Deaths per 100,000.	Year.	Deaths per 100,000.
1898	189	1900	128	1902	109
1899	78	1901	24	1903	160

Ford City, Pa.—Ford City, Kittanning's near neighbor, had a similar experience in the epidemic conditions prevailing from March 24, 1903, to January 23, 1904, in which period eleven deaths from typhoid fever occurred, in an estimated population of 3,000.

KISKIMINITAS RIVER BASIN.

CONEMAUGH RIVER.

Johnstown, Pa.—Johnstown (population about 40,000) is on Conemaugh River, the principal tributary of the Kiskiminitas. It has a sewer system draining into the river. This important city takes its water supply entirely from mountain runs impounded in an extensive system of storage reservoirs, holding a total of 283,000,000 gallons, beside which there are two intakes on Conemaugh River for supplying manufacturing plants through a 36-inch cast-iron main. For the town supply, however, only the reservoir water is now used, and the watershed is said to be regularly patrolled by special constables. The greater portion of the drainage area is owned by the Johnstown Water Company and much of the remainder by the Cambria Steel Company. The two corporations are said to work together in policing the entire drainage area. It would seem that radical measures are necessary to bring this town into the class of cities having a moderate death rate from water-borne diseases, for

[a] Eng. News, Feb. 11, 1904.

it has been a plague-spot of typhoid fever for many years, as is shown by the following statistics:

Typhoid mortality at Johnstown, Pa.

Year.	Population.	Total deaths.	Typhoid deaths.	Typhoid death rate per 100,000.
1891	21,805	....	10	46
1892	22,000	....	5	22.7
1893	23,300	....	13	56
1894	23,800	....	10	42
1895	25,000	....	16	64
1896	....	427	21	....
1897	26,000	....	21	81
1898	32,000	459	10	31
1899	35,936	586	28	78
1901	37,000	689	40	108
1902	40,000	717	14	35

These figures indicate that the water supply of Johnstown is among the worst in the country. The sudden drop in 1902, if permanent, may be the result of more careful inspection by the new management. The five deaths of 1892 were all traced to pollution of a reservoir by the drainage from a cesspool on a farm about 1½ miles above. This had received dejecta from a typhoid patient, which, washing down into the reservoir, caused the infection of consumers of the water.

The daily consumption is about 3,000,000 gallons. With the amount in storage the town has an abundant supply before drawing upon the Conemaugh. The month's drought in the fall of 1904 which proved so serious throughout this section necessitated the use of river water after public notice. Since then the storage capacity of the reservoirs has been increased 130,000,000 gallons, making the total above stated. Comparison of the quality of the two supplies is decidedly in favor of the mountain water.

Field assays of water in Kiskiminitas River basin.

[Parts per million.]

Determination.	Indiana.	Johnstown. Public supply.	Johnstown. Conemaugh River.	Johnstown. 100-foot well, Hotel Crystal.
Turbidity	0	0	0	0
Color	40	96	22	27
Iron (Fe)	(a)	1	1	(a)
Calcium (Ca)	30	0	68	35
Total hardness (as $CaCO_3$)	37	22	63	60
Alkalinity	47	11	8	170
Sulphates (SO_3)	[b] 5	0	56	41
Chlorides (Cl)	8.2	4.5	7.7	141

[a] Very slight trace. [b] Estimated.

The Johnstown public supply is very soft and pure; but the high color suggests some marshy drainage. The water of Conemaugh River is much harder and makes serious trouble in boilers, and is, besides, so contaminated at times as to make its use for domestic purposes inadvisable without filtration. The well water is very much harder than the city supply.

Indiana, Pa.—Indiana (population about 5,000) on Marsh and Whites runs, branches of Two Lick Creek, which drains into Conemaugh River, has an unfiltered supply from the creek.

The chief trouble with the water supply seems to be the lack of sanitation on the creek. As far as mineral contents go, the water is of fair quality.

KISKIMINITAS RIVER BELOW COMEMAUGH RIVER.

Vandergrift, Pa.—Vandergrift (population about 5,000) has a combination spring and well water supply, and Apollo, near by, pumps from Kiskiminitas River. Both drain into the Allegheny, and the typhoid-fever figures given indicate the character of this contribution to the river water.

ALLEGHENY RIVER BETWEEN KISKIMINITAS RIVER AND PITTSBURG.

The quality of the water of Allegheny River below Kiskiminitas River is described under the heading "Natural filtration," page 57.

SUMMARY OF CONDITIONS IN ALLEGHENY RIVER BASIN.

The work of the Pittsburg filtration commission showed conclusively that in a watershed of the "quick-spilling" class, like the Allegheny, even a scattered population, not collectively a great number as compared to a great city, can and does pollute the main stream to a degree that makes its water undesirable and dangerous for drinking.

The foregoing study shows that typhoid fever exists in some form at all points on the river and its important tributaries. Owing to the character of the physical features of the country this contamination may enter the stream at any point and be delivered in virulent form at any other point below. The profile sheet (Pl. III) shows that the slope of Allegheny River is rather abrupt. The elevations used in platting in many cases represent only approximately the actual level of the river, and the distances are partly scaled from a map. This inaccuracy of data is of no consequence in a chart drawn to the scale shown, the actual differences being far too small to plat, so that the profiles given faithfully represent actual conditions.

At Port Allegany, near the source of the stream, the elevation is 1,479 feet; at Franklin, where French Creek joins the main stream, the elevation is 969 feet, a drop of 510 feet in 145 miles, or about 3.5 feet per mile. This is not an exceptionally steep grade, many irrigation canals of the West, built in earth, having a fall, roughly speaking, of 1 to 5 feet per mile, without ordinarily acquiring a velocity sufficient to damage their banks. In view of the resistance offered to the flow of water in the open channel by rocks and unevennesses of surface, it is evident that the velocity given by the slope of the river bed is not sufficient to account for the rapid delivery of storm water to a point near Pittsburg.

The character of the watershed is a factor whose importance can be surmised when one recollects the numerous and destructive floods in this stream. The sides of the valley through which the river flows are steep and the soil does not absorb water readily. Besides, numerous side gorges dissect the country in every direction, with slopes so abrupt as to deliver storm water in torrents to the main stream. Even the larger tributaries have very steep grades. This is clear from the profiles of the comparatively large tributaries, French Creek and Clarion River. Between Corry and Franklin, where it enters the Allegheny, French Creek descends 457 feet in a distance of about 70 miles, making a grade of about 6.5 feet to the mile—a slope about twice as steep as that of the main stream. Clarion River, between Ridgway and its mouth, a distance of 58 miles, has a fall of 514 feet, or 8.9 feet to the mile. The facts seem to be, therefore, that a valley with a gradient in the main as low as 3.5 feet to the mile will deliver storm water very rapidly if its side slopes are steep and covered mainly with a somewhat impervious soil.

The significance of these conditions and the justness of the judgment thereon by the filtration commission's experts will be made clear by the following description of the Monongahela River drainage.

MONONGAHELA RIVER BASIN.

DESCRIPTION OF BASIN.

Monongahela River is formed by the junction of several streams, the largest being the Youghiogheny, which enters at McKeesport. Above this point the largest tributary is Cheat River, which furnishes the greater portion of the water in the Monongahela the year round. The drainage area of this stream as well as that of West Fork and of Tygart River, other tributaries of the Monongahela, is very sparsely populated, the towns being few, small, and far between. The total population of the Monongahela River drainage area in 1900 was almost identical with that of the Allegheny, each consisting of about 184,000 people.

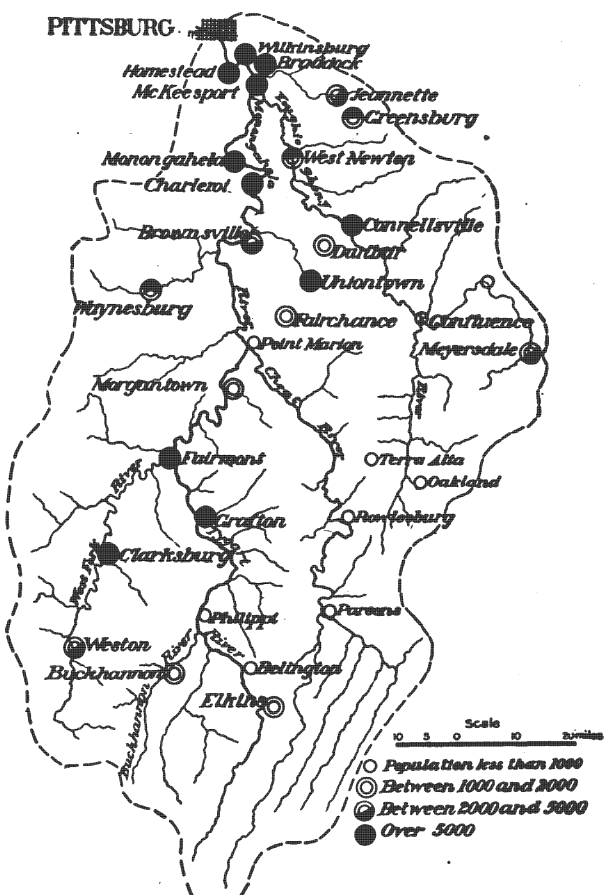
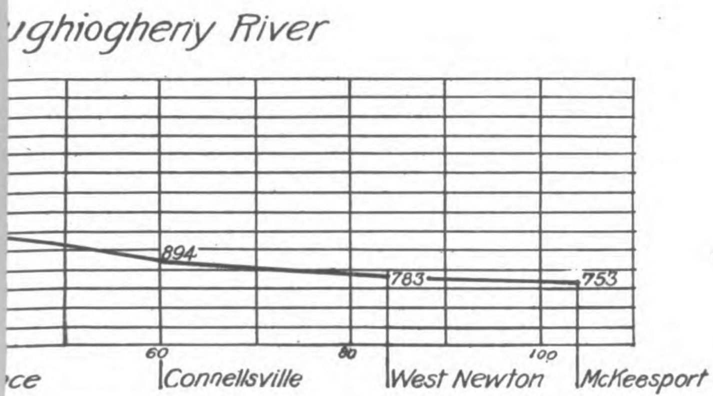
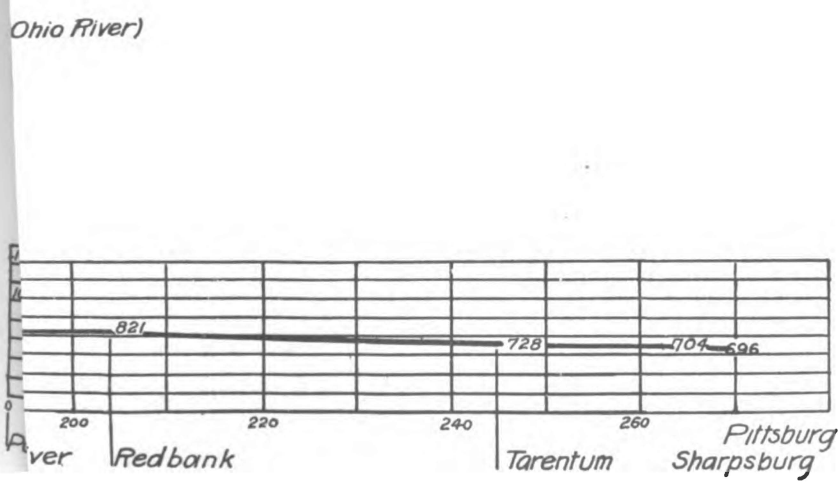


FIG. 2.—Map of Monongahela River basin, showing population.

TYGART RIVER ABOVE BUCKHANNON RIVER.

Tygart River is a rapid stream flowing over naked rock (Pl. II, *B*, p. 26) in nearly the whole of its course, through very thinly inhabited country. The heavy timber in its drainage area was cut long ago, so that very little lumbering is now carried on there, with its too frequent accompaniment of pollution of the running streams. The profile of this river (Pl. III) points to the fact that on account of the rapidity of its flow there can be but little


ughiogheny River
894
783
753
60
80
100
ce
Connellsville
West Newton
McKeesport


Ohio River)
821
728
704
696
200
220
240
260
ver
Redbank
Tarentum
Pittsburg
Sharpsburg

self-purification of its water, the pollution not being detained long enough in the water to permit much sedimentation.

Elkins, W. Va.—The town nearest to the source of Tygart River is Elkins (population, about 2,500), whose water supply is pumped directly from the river without purification. A field assay of this water is given on page 33. In view of the very scanty population above Elkins, a little intelligent sanitary inspection should insure a good supply, the water being as a rule exceptionally pure and clear. There is, however, more or less pollution at all times from privies and farms along the stream, putting the city in the position of drinking from a beautiful reservoir of clear water which is liable to contamination by every one working along the river. The sewage of Elkins drains into Tygart River, and as the flow of the stream is swift the harmful character of this contribution is not much lessened in the short time it traverses the 15 miles between Elkins and Belington.

Belington, W. Va.—Belington, a town of possibly 800 population, draws its supply directly from Tygart River. It seems certain that more or less pollution from Elkins sewage is bound to come down as far as Belington; besides the same liability to careless or wanton pollution that exists above Elkins would operate to make the water unsafe for Belington. Sanitary inspection of the stream is needed. A field assay of water from Tygart River at Belington is given on page 33.

BUCKHANNON RIVER.

Buckhannon River enters the Monongahela at Tygart Junction, about 12 miles below Belington, carrying at least as much water as Tygart River does up to that point.

Buckhannon, W. Va.—The only town on this tributary is Buckhannon (population, 2,500), whose water supply is drawn directly from Buckhannon River, which is backed up for several miles above the city by an old milldam. The intake of the pumping station is above the points of exit of the sewage from the city. The plant is operated in connection with a modern ice plant using sterilized water. The same laxity exists here as at Belington and Elkins as regards sanitary inspection of the stream.

Field assays of water from Buckhannon and from Buckhannon River.

[Parts per million.]

Determination.	Buckhannon.		Buckhannon River at Tygart Junction.
	40-foot well.	City supply.	
Turbidity	0	0	0
Color	45	35	50
Iron (Fe)	2.5	Trace.	(a)
Calcium (Ca)	102	0	0
Total hardness (as $CaCO_3$)	130	28	32
Alkalinity	83	12	12
Sulphates (SO_3)	5	0	0
Chlorides (Cl)	29	9	9

a Slight trace.

The well water is obtained from a well that some years ago caused a typhoid epidemic by becoming infected with drainage from neighboring privies. The water is characteristically hard and would be very poor for any industrial or domestic use, and the liability of the well to pollution from infected drainage makes it best to avoid it as a source of water for drinking. The two analyses of the river water show practically the same mineral content and indicate that it is a very excellent water, suitable for any manufacturing or boiler purposes.

The great objection to the Buckhannon water lies in the deliberate pollution that goes on all along the river above the town. For 40 miles above Buckhannon the stream winds

through forest country having a very scanty population scattered along the banks. There are eight or ten little villages along the course of the stream, and every one of them has at least two or three privies overhanging the water.

Pickens, W. Va.—Pickens, a town at the head of the river, having a population of a few hundred, is built on the steep slopes of a little valley draining into the stream. At the railroad station the privy stands directly over a tributary within 40 yards of the main stream. Farther downstream, at the mill, there are two or three more privies located directly on the stream itself. With this pollution going down the river, reinforced every few miles with more, it is difficult to see how Buckhannon water can be safe. The only protection the consumers have is the 7-mile sedimentation basin into which the river at Buckhannon has been turned, giving the pollution a chance to settle.

Field assays of water from Pickens, W. Va.

[Parts per million.]

Determination.	10-foot well.	100-foot well.	Spring.
Turbidity	0	0	0
Color	17	70	5
Iron (Fe)	[a] .5	18	0
Calcium (Ca)	76	62	....
Total hardness (as $CaCO_3$)	90	104	28
Alkalinity	24	78	22
Sulphates (SO_3)	[a] 20	[a] 10	0
Chlorides (Cl)	19	19	9

[a] Estimated.

The spring furnishes a typical water of this class—soft and pure. The high mineral content of the shallow well points to a characteristic rock water, the rock being within a few feet of the surface and dipping down the hill to where the 100-foot well is located. The latter is used in boilers with unsatisfactory results, as might be expected from the assay.

TYGART RIVER BELOW BUCKHANNON RIVER.

Philippi, W. Va.—The village of Philippi (population about 1,000) is located on Tygart River, about 15 miles below Belington and about 12 miles below Buckhannon. As the sewage from the towns already mentioned pollutes the stream, it is not believed that the Philippi supply is safe, pumped as it is directly from the river without purification. It should be borne in mind that while these streams do not receive a great deal of pollution from any one of these towns, the amount of water in the river beds becomes very low in the summer and fall, so that the beneficial effects of dilution, if there are any, must be very slight, and at the same time sedimentation and storage probably play no part at all in the purification of the water, owing to the high velocity of the streams.

Although the water is naturally very pure and these little towns are about 15 miles apart, it seems certain that purification in a stream so small and rapid is not sufficient to warrant the use of the water for drinking after infection from even a few families has entered the stream. Although the drainage area as far down as Grafton is so sparsely inhabited that pollution from all sources except city sewage is extremely slight, the rugged nature of the country allows storm water to enter the stream very rapidly, increasing the liability to wash down infection. Nevertheless, the water remains very clear a great deal of the time, there being comparatively little fine soil to be washed away.

Grafton, W. Va.—Grafton (population about 5,000) is about 20 miles down the river from Philippi. The city supply, amounting to about 500,000 gallons a day, is drawn direct from the Tygart River without purification. As very little sewage is added to the

stream from Philippi, there is a stretch of about 35 miles that may be regarded as relatively free from pollution above Grafton. Distance, however, in the absence of conditions permitting sedimentation, is of no avail in purifying river waters, and it is believed that this water is not safe for drinking purposes without treatment. There is so much wanton defilement in small amounts along the stream that anyone who follows its course from its source to Grafton will not be inclined to drink the raw water at any point. The city of Grafton has never taken proper care of its water supply. Until a few years ago the intake of the city system was a little below the town, so that the people of the town were drinking a dilution of their own sewage. The consequent high typhoid rate resulted in the removal of the intake up the stream, by which the conditions were somewhat improved. Filtration of the supply, however, is absolutely necessary to make the water safe.

The change in chemical content below Belington is striking, the hardness and alkalinity both being reduced about 50 per cent at Tygart Junction and the hardness still further reduced at Grafton. The reduction is probably due to the acid mine drainage along the course of the stream neutralizing the alkaline carbonates to a great extent and causing the precipitation of some of the calcium carbonate. The amounts of these present are so very small that this water is exceedingly pure, usable for any industrial purpose in its raw state.

Between Grafton and Fairmont the river flows through a country that is somewhat more rolling than that at the headwaters. There is little population, only a few hamlets being on the stream. It is noticeable, however, that every one of them has houses draining into the stream, so that pollution in small quantities is constantly entering it. There are no public supplies at these points, the inhabitants all using individual wells.

Field assays of water from Tygart River at points in West Virginia and of well water from Colfax, W. Va.

[Parts per million.]

Determination.	Elkins.	Belington.	Tygart Junction.	Grafton.	Colfax.	
					53-foot well.	36-foot well.
Turbidity	0	0	0	0	0	0
Color	83	180	35	22	17	0
Iron (Fe)	[a] .5	4	0	Trace.	10	0
Calcium (Ca)	0	....	0	0	52	133
Total hardness (as $CaCO_3$)	45	45	21	7	139	139
Alkalinity	25	23	13	14	96	14
Sulphates (SO_3)	0	0	0	0	0	155
Chlorides (Cl)	9	9	14	9	19	34

[a] Estimated.

The well waters are both in the rock, possibly in the coal seam which was uncovered at the depth of about 35 feet in building the abutments for the bridge at this point. They are both very hard. That of the 53-foot well destroys tinware rapidly, probably by the action on the metal of free CO_2 in the water. It is possible also that the iron is present as ferrous bicarbonate ($FeH(CO_3)_2$), which is decomposed in contact with the metal, giving off a little free CO_2.

WEST FORK RIVER.

At Fairmont Tygart River unites with West Fork River to form the Monongahela. West Fork River is a stream of very different character from the one just discussed. As may be seen from the profile sheet, it is practically a series of pools connected by the running stream, with a very slight fall, so that purification may go on to a great degree by the influence of sedimentation and storage. The stream is also very turbid during a large

portion of the year. This adds to the possibility of purification by the heavy particles settling in the pools and carrying down the bacteria.

Weston, W. Va.—The city of Weston (population 3,000) is nearest the head of the stream. Above it there is no sewage and a scattered and scanty population. The public supply is pumped directly from West Fork River, about 200,000 gallons a day being used. The supply is to be criticised in three respects. In the first place, it becomes very scarce during the summer. Secondly, the turbidity is high at certain seasons of the year. The drainage area of this stream is different from that of Tygart River in that there is a deeper soil and much more land in cultivation, so that the frequent rains wash down much fine yellow clay, which settles very slowly in the water. The third objectionable feature, hardly less serious than the insufficient quantity, is that besides the organic matter which is washed into the stream above Weston from the dwellings and farms along the shores, the stream is wantonly polluted above the intake of the waterworks. There are several privies on the other side of the river from the waterworks just a few feet above the dam.

On the whole, a great deal of improvement is needed in the town's water supply before it can be said to be satisfactory. The water company is contemplating the purchase of a mill site farther up the river, which will add about 40,000,000, gallons of storage. If this purchase is made and vigorous measures are taken to police the area adjacent to the river, the result will be an immense improvement in the quality of the water.

The quality of ground water which it is possible to develop here for municipal use is indicated by the field assays, given herewith, of water from three deep wells sunk in search of oil and gas. The quantity of water obtained from these wells is ample. In quality the water is fairly good for drinking purposes, though too high in mineral matters for commercial use. The wells are located rather close together, the Irvin and Woodford wells being on opposite sides of the river, about a quarter of a mile apart and the Maxwell well about 2 miles distant. The remarkable agreement in the quality of the waters of the two former would seem to indicate that they are from the same water horizon. It is believed that a chain of wells sunk to the depths indicated would yield an ample water supply for the town of Weston. Such a supply could not, however, be used in boilers without treatment.

Field assays of ground water from Weston, W. Va.

[Parts per million.]

Determination.	Ervin well; 700 feet deep.	Woodford well; 700 feet deep.	Maxwell well; 635 feet deep.
Turbidity	0	0	0
Color	20	20	35
Iron (Fe)	2	2	0
Calcium (Ca)	53	65	28
Total hardness (as $CaCO_3$)			104
Alkalinity	392	393	440
Sulphates (SO_3)	0	0	0
Chlorides (Cl)	488	499	426

These waters are all hard rock waters, suitable for drinking purposes, but high in incrusting and corroding solids, and therefore unfit for use in boilers. The chlorides corrode the tubes rapidly, and no treatment has yet been discovered that will prevent this action.

The water of West Fork River itself is very similar in mineral content to that of the two streams discussed above. The field assay is supplemented by an analysis furnished by the Baltimore and Ohio Railroad Company made in October, 1900:

Field assay of water from West Fork River and analysis of water from pool.

Field assays.	Parts per million.	Analysis.	Parts per million.
Turbidity	[a] 2	Iron and alumina ($Fe_2O_3+Al_2O_3$)	54
Color	70	Calcium	6
Iron (Fe)	0	Magnesium	3
Calcium (Ca)	tr.	Sodium	13
Total hardness (as $CaCO_3$)	35	Chlorine	19
Alkalinity	30	Sulphate radicle	22
Sulphates (SO_3)	0	Carbonate	2
Chlorides (Cl)	12	Color, brown.	

[a] Estimated.

REMARKS BY ANALYST: Full of organic matter; rotten odor; unfit for use.

When the stream becomes very low in the fall, it is of uninviting appearance in the pools, and this feature makes the present supply most unsatisfactory.

Clarksburg, W. Va.—Clarksburg (population about 6,000) is about 22 miles down West Fork River from Weston. The city supply is pumped without purification from West Fork River. Between Weston and Clarksburg there is considerable rural population, the land being rolling and fertile. Although farm pollution takes care of itself to a large extent, a portion at least of the drainage from the farms finds its way into Elk Creek and West Fork River. The most important factor of pollution, however, is the sewage from Weston. If there were always plenty of water in the river its extremely low rate of flow might insure sufficient detention of the sewage to cause a high degree of purification. The stream becomes so nearly dry, however, that, as at Weston, isolated pools have to be drawn upon for the city supply at certain seasons of the year. Plans are under way for rebuilding the Clarksburg pumping plant and adding to it a settling basin. If efficiently operated this will improve the appearance of the water and probably lower the bacterial content to some extent. It is not believed, however, that this water is safe for public supply without filtration. It is claimed by the townspeople that it is not used for drinking, spring and well water being sold and used extensively. A similar claim is made in nearly every town in West Virginia that has a bad water supply; but in most cases the statement is not warranted by the facts. Experience has shown that no matter how bad the quality of the water, if it has not an offensive appearance and odor, and frequently if it has, a large percentage of the population on the taps will drink it habitually, trusting to luck to escape disease. It is safe to assume that every dangerous public water supply in West Virginia—and there are many of them—which it is claimed by the residents is used only for washing, is being drunk by precisely those who should not drink it—the poorer inhabitants, who can not buy pure water or take care of themselves after they are infected.

West Fork River water would not be unusually difficult to filter, the experience of the Hotel Waldo with a small Loomis apparatus, with alum sedimentation, being very encouraging. This device is in the form of a compact tank inclosing a so-called cutting plate or diaphragm screen, through which the sand has to pass up and down in washing, breaking up the dirty material caught on the sand. An assay of the water treated with this apparatus shows a remarkable improvement in quality, due largely to the heating of the raw water.

Three analyses of ground water from wells at Clarksburg are given below. These waters are derived from widely different levels, the shallowest being in one of a group of flowing wells 46 feet deep at Union Heights. This well furnishes water for domestic use, but like the 160-foot well of the Standard Milling Company its yield is not sufficiently great to make it important for anything but private supply. Not until the drill is sunk to the extreme depth shown at the Hotel Waldo—500 feet—is a body of water found great enough to stand pumping. Its quality, however, approximates that of mineral water, its chlorine and iron

contents being extremely high. The well, which is a 4-inch one, was pumped all summer and supplied a large portion of the town until the excessive drought of 1904 so exhausted the stratum as to necessitate a stoppage of pumping. It would seem, however, that an adequate city supply could be obtained by drilling a number of wells; but the expense of this system and the fact that the water is unfit for boiler use indicates that it would be better and cheaper to install a plant for mechanically filtering the water of West Fork River.

Field assays of water from Clarksburg, W. Va.

[Parts per million.]

Determination.	46-foot flowing well, T. J. Francis.	160-foot well, Standard Co.	500-foot well, Waldo Hotel.	West Fork River.	
				Raw.	Filtered.
Turbidity	0	0	0	(a)	0
Color	0	17	27	88	17
Iron (Fe)	0	6.5	24	[b]1.5	2
Calcium (Ca)	88	56	64	0	0
Total hardness (as $CaCO_3$)	104			63	21
Alkalinity	312	257	381	20	14
Sulphates (SO_3)	0	(c)	0	[b]10	0
Chlorides (Cl)	60	19	423	9	4

[a] Decided. [b] Estimated. [c] Very slight trace.

The well waters are too high in mineral contents to be used in industrial plants without treatment. The river water is shown in its natural state and as improved by filtration with the Loomis apparatus, the process rendering it extremely soft and the diminution in bacterial content making the effluent safer for drinking. It is not known whether the process can be made cheap enough for use on a large scale.

Salem and Wallace, W. Va.—Salem and Wallace, on the branch lines of the Baltimore and Ohio Railroad radiating from Clarksburg, present conditions typical of towns that rely on ground water for their supply. Salem (population 700) derives its supply from six wells, about 100 feet in depth, all in the sandstone, the source of all the drilled-well water in this section. The first water stratum is tapped at about 56 feet. Springs in the section are neither numerous nor strong and practically all fail in times of drought.

The spring water is considerably more mineralized than the pure mountain springs in this drainage area, yet it may be considered a soft water. The public supply (assay on p. 37) is very hard, not usable for industrial or boiler purposes without treatment. The high alkalinity suggests the presence of alkaline carbonates, besides the calcium compounds.

At Wallace, W. Va., a little oil town (population 400) there is no public supply. The town is built along a little creek draining into West Fork River, and in every case where it was possible to do so the outhouses have been constructed to overhang the creek, the latter becoming practically an open sewer.

The extensive drilling for oil has developed the geological structure in this section enough to show that water may be had at depths ranging from 20 to about 200 feet—in large quantity and reputed good quality—at the latter depth. The assays (p. 37) are of water from shallower wells in common use, the 108-foot well being on a farm at the edge of the town. Most of the shallower wells become very low in summer.

The water from the 108-foot well is remarkable for its softness, the probability being that the carbonates are present as sodium and potassium carbonates, and that calcium and magnesium are lacking. As the great difficulty with the ground waters of northern West Virginia is their hardness, which unfits them for boiler uses, this well is important as indicating a vein of soft water at this depth. The other water assayed is fair, the incrusting

solids being chiefly calcium carbonate. The yield from the well furnishing this is small, sufficient only for a half dozen families.

Shinnston, W. Va.—Between Clarksburg and Fairmont there are many small coal-mining camps and coke ovens. Shinnston (population 600), on West Fork River, is the largest of these places. The public supply is pumped unpurified from the river into a 1,000-barrel tank. This is said to be used for fire service only, drinking water being obtained entirely from shallow wells 10 to 40 feet deep, the depth depending on the elevation of the top of the well, the water in all being derived from beds at the same horizon apparently. The town is located just below the Pittsburg coal seam, which is pierced at East Shinnston, about 3 miles farther northeast, where there are flowing mineral wells. Some years ago a drilling made through the first rock (40 feet) by William Blair gave good water in great quantity. There is the usual string of outhouses overhanging the river.

Field assays of water from Salem, Wallace, and Shinnston, W. Va.

[Parts per million.]

Determination.	Salem.		Wallace.		Shinnston.
	Spring.	100-foot well.	42-foot well.	108-foot well.	
Turbidity	0	0	0	0	0
Color	45	45	10	166	45
Iron (Fe)	0	1	Trace.	1.25	1.5
Calcium (Ca)	....	156	53	0	100
Total hardness (as $CaCO_3$)	56	....	77	25	139+
Alkalinity	19	249	180	103	73
Sulphates (SO_3)	0	47	0	0	47
Chlorides (Cl)	19	59	29	29	59

MONONGAHELA RIVER FROM TYGART RIVER TO CHEAT RIVER.

Fairmont, W. Va.—Fairmont (population 5,000), about 30 miles below Clarksburg, pumps Monongahela River water for filtration. This was formerly effected by two mechanical filters of the Buffalo type, but during the summer of 1905 two slow sand filters 75 feet square were installed and are now used. With proper operation of these filters the city ought to have an excellent water supply, the mine drainage up to this point not being sufficient to make the water objectionable and the other mineral impurities being slight. Analyses of the raw and the filtered waters, given below, agree very closely.

Field assays of Monongahela River water at Fairmont, W. Va.

[Parts per million.]

Determination.	Raw water.	Filtered water.	Determination.	Raw water.	Filtered water.
Turbidity	0	0	Total hardness (as $CaCO_3$)	35	35
Color	83	83	Alkalinity	14	14
Iron (Fe)	[a] .8	[a] .8	Sulphates (SO_3)	[a] 5	[a] 5
Calcium (Ca)	([b])	Trace.	Chlorides (Cl)	9	9

[a] Estimated. [b] Slight trace.

The three analyses following, furnished by the Baltimore and Ohio Railroad Company, show that the variation in quality at different seasons of the year is great enough to cause considerable difficulty in handling the water, either in filtration for drinking or in treatment for industrial purposes.

Analyses of water from Monongahela River at Fairmont, W. Va.

[Parts per million.]

Determination.	Feb. 26, 1900.	June 9, 1903.	Sept. 26, 1903.
Color	(a)	(b)	Slight.
Turbidity	(c)	Decided.	Slight.
Calcium (Ca)	8.9	7.2	25
Magnesium (Mg)	1.8	2.6	5
Carbonic acid (CO_3)	11.6	12.8	9
Sulphuric acid (SO_4)	9.9	7	65.8
Iron and alumina (Al_2O_3 and Fe_2O_3)	10.3	32	5
Alkali chlorides	3.2	9	23.3
Alkali sulphates	0	0	13
Total solids	45.7	70.6	146.1

[a] Yellowish, clay. [b] Yellow, muddy. [c] Considerable.

The variation in total solids is seen to be as high as 100 per cent between June and September, though the June sample was taken after a heavy rain.

Buffalo Creek, which enters the Monongahela at Fairmont, drains an extensive country having a population of several thousand. The most important town is Mannington (population 2,500), which has a very complete waterworks system. The supply is derived from 11 wells, 100 feet in depth, driven close together near the creek about half a mile from town. As it was feared that summer demands would make it necessary to draw upon the polluted waters of the creek, a mechanical filter was installed for treating the creek water. It is claimed that up to date it has not been necessary to use the filter. The creek carries the town sewage as well as that of Farmington and other small communities, receiving also drainage from numerous coal camps along its course. A field assay of the water is given on page 39.

It should now be sufficiently evident that from this point on down stream the Monongahela River water is dangerous for drinking purposes unless it can be shown that it has completely purified itself by sedimentation in the lower reaches of the river. The influence of the Weston and Clarksburg sewage in a stream so small and so subject to failure as West Fork River certainly extends as far as Fairmont. Besides this the pollution from Grafton must necessarily add much fresh contamination to the stream above Fairmont. That city is considering the removal of its waterworks intake so as to draw from Tygart River, which would certainly be better than the present source, for the West Fork contamination would thus be completely eliminated.

Morgantown, W. Va.—Morgantown (population 1,800), about 20 miles farther down the stream, has one of the most complete waterworks systems in West Virginia. The water is pumped from Monongahela River into a settling basin, whence it passes to four mechanical filters. There is no clear-water reservoir, the filtered water going directly into the mains to the average amount of 1,200,000 gallons a day. The water seems to be satisfactory. The old gravity supply, from a mountain stream about 6 miles from the town, has been allowed to fall into bad repair with the perfection of the filtration plant on the river.

Field assays of water from Mannington and Morgantown, W. Va.

[Parts per million.]

Determination.	Mannington.		Morgantown, city supply.
	City supply.	Buffalo Creek.	
Turbidity	0	386	0
Color	17	(a)	96
Iron (Fe)	.5	0	1
Calcium (Ca)	52	....	Trace.
Total hardness (as $CaCO_3$)	63	70	35
Alkalinity	163	47	20
Sulphates (SO_3)	[b]20	0	0
Chlorides (Cl)	24	19	14

[a] Too high to read. [b] Estimated.

For industrial purposes requiring a water free from any acid content this water might not prove satisfactory at certain seasons on account of the mine drainage emptying into the stream. Otherwise it is of good quality, very suitable for a public supply.

CHEAT RIVER.

At Point Marion, Pa., Monongahela River receives its great tributary, the Cheat. This fine stream flows for much of its length through a deep canyon in rough country, having almost no population on the watershed. There are but three important villages on the stream, none of them having over 800 people. The pollution from these is very slight, none of the towns being sewered, so that the most serious contamination is from the sawmills and tanneries on the river. A profile of Cheat River is shown on Pl. III, page 30.

Shavers Fork and Dry Fork, which unite to form Cheat River, at Parsons, carry waters of good quality which differ only in the trace of sulphate in that of the former. (Assays on p. 40.) The higher color of Dry Fork is due to tannery pollution, which persists in the main stream a mile or two lower down, as is shown in its equally high color. Both the color and the sulphur-trioxide content diminish markedly in the course of the flow to Rowlesburg, about 20 miles down the river, and in this stretch there is also a slight temporary diminution of the alkalinity. (See assay on p. 40.)

Parsons, W. Va.—At Parsons (population 600), at the junction of Shavers Fork and Dry Fork, there are two tanneries, the effluents from which stain the water perceptibly. Sawmills are located at various points along the stream, but, as the merchantable timber will soon be gone, pollution from these may be regarded as only temporary. In its present state the water of the river is exceptionally fine, not greatly contaminated by sewage, and the flow is sufficient to supply a million people. A field assay is given on page 40. The drawback to its use, however, lies in the extremely steep grade of the stream, which is shown on the profile sheet. The very rapid fall evidently makes self-purification almost impossible, and it is by no means improbable that typhoid fever contamination far up on the headwaters of the stream may be delivered in virulent form at points as far down as its mouth, or even in Monongahela River itself.

Tunnelton, W. Va.—The divide between the Cheat and the Youghiogheny is very narrow at the highest point, which is Tunnelton, W. Va., a village of about 500 inhabitants. There is practically no permanent water supply here; the supplies are derived from individual wells not over 50 feet in depth, nearly all of which dry up in spells of drought. Much money has been expended by the coal company in boring for water, without success; and it may yet be necessary to pump from the river, costly as such an expedient may be.

The well assayed (p. 41) furnishes water longer than the majority in dry times. The water is of very poor quality for any purpose except drinking. The very low alkalinity

would indicate that the calcium present occurs as calcium sulphate and chloride, with similar salts of magnesium, and probably very little alkaline salt.

Point Marion, Pa.—Point Marion (population about 600) has diverted a small portion of the flow of Cheat River into an earth reservoir some miles above, holding about 1,000,000 gallons. At Point Marion the mineral content of the water is practically the same as at Parsons, 60 miles upstream. The water is of excellent quality for all industrial purposes. The daily consumption is about 60,000 gallons, of which half is used by the Baltimore and Ohio Railroad Company. Figures as to typhoid fever are available for only two years, but their evidence is strong as to the unhealthfulness of the raw water.

Typhoid mortality at Point Marion, Pa.

Year.	Population.	Total deaths.	Typhoid cases.	Typhoid deaths.
1899	550	2	5	1
1900	575	10	15	3

The significance of these figures will be understood from the fact that in Allegheny City there were, in 1899, 895 cases of typhoid fever reported, the population by the census of 1900 being 129,000; in other words, 0.7 per cent of the population contracted the disease in one of the worst typhoid plague spots in the world, while here in Point Marion in 1899 0.8 per cent of the whole population and in 1900 2.6 per cent were ill with typhoid fever. The evidence is strong that the infection was general. Such conditions are usually chargeable to the quality of the water and seem to settle the class in which raw Cheat River water belongs, as the public supply is widely used. Incidentally, the figures are important in further suggesting that rivers with such a high rate of flow as the Cheat, and with such a quick-spilling watershed, do not purify themselves appreciably in their courses—in this case about 60 miles.

Field assays of water from Cheat River basin.

[Parts per million.]

Determination.	Dry Fork at Parsons.	Shaver Fork at Parsons.	Cheat River at Parsons.	Cheat River at Rowlesburg.	Cheat River at Point Marion.
Turbidity	0	0	0	0	0
Color	106	61	106	60	78
Iron (Fe)	[a]0.5	1	0.8	1.5	1
Calcium (Ca)	Trace.				
Total hardness (as $CaCO_3$)	35	35	32	35	35
Alkalinity	25	17	19	14	22
Sulphates (SO_3)	0	[a]20	[a]20	([b])	([b])
Chlorides (Cl)	9	9	9	14	9

[a] Estimated. [b] Very slight trace.

MONONGAHELA RIVER FROM CHEAT RIVER TO YOUGHIOGHENY RIVER.

Where Cheat River enters the Monongahela, at Point Marion, the difference in the clearness of the waters of the two streams is strongly marked, a sharply defined line appearing right across the mouth of the stream where the clear water of the Cheat meets the muddy yellow water of the main stream. From this point on to Greensboro, Pa., a distance of perhaps 12 miles, the steep slopes of the tributary streams quickly disappear, until the Monongahela River becomes practically a series of slack-water basins, extending from Greensboro to Pittsburg.

Waynesburg, Pa.—Waynesburg, with a population of about 2,500, is at such a distance from Monongahela River, about 22 miles, as to make its drainage of slight importance in the discussion of that stream.

It has a mechanically filtered supply from Tenmile Creek, pumped to a distributing reservoir, and the company is now improving the plant, placing fresh sand and gravel. The water is very hard for a surface supply, and is unsuitable for laundry or industrial uses. (See assay below.) Although few figures concerning typhoid fever are available, those given below show that in the main the filters have been a protection in the past:

Typhoid mortality at Waynesburg, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1894	....	7	1
1895	....	27	4
1896	....	1	....
1897	....	4	....
1898	37	8	1

The figures for 1895 show a general infection, possibly traceable to the water supply.

Fairchance, Pa.—The borough of Fairchance (population 1,200), situated between Monongahela and Youghiogheny rivers, drains into a small creek emptying into the Monongahela. There is no public supply, water being drawn from individual wells of the kind noted below. The town's contribution to the drainage is not innocuous. Records of typhoid-fever mortality are available for this place only for 1896 and 1897, but they show a grave situation in those years.

Typhoid mortality at Fairchance, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1896	20	80	8
1897	13	4	1

The figures for 1896 point to either a general infection from one source or a general use of water from contaminated wells. The drainage from a town with such a record of typhoid deaths certainly can not improve the quality of any water.

Field assays of water in Monongahela basin.

[Parts per million.]

Determination.	Tunnelton, W. Va., 30-foot well.	Waynesburg, Pa., public supply.	Fairchance, Pa.	
			39-foot well (Richey).	77-foot well (J. W. Byers).
Turbidity	0	0	0	0
Color	11	35	57	22
Iron (Fe)	Trace.	Trace.	0.8	1.5
Calcium (Ca)	179	81	173	0
Total hardness (as $CaCO_3$)	130+	130+	132	....
Akalinity	10	97	77	228
Sulphates (SO_3)	106	[a]10	[a]20	[a]20
Chlorides (Cl)	70	5.6	19	39

[a] Estimated.

Both the Fairchance waters are hard rock waters, unfit for laundry use. The carbonates of the 77-foot well are probably those of magnesium or the alkalies. If properly cased either one would make a good drinking water, in spite of the red deposit formed by the oxidation of the iron a few hours after the water is drawn.

Uniontown, Pa.—The city of Uniontown, Pa. (population 10,000), has a gravity supply from large mountain springs. The water is of excellent quality and suitable for any purpose (see assay on p. 44), but the supply proves entirely inadequate as soon as the summer drought sets in. In 1904 the necessities of the town were so urgent that arrangements had to be made at considerable cost with the water system of the H. C. Frick Coal and Coke Company, which has large coking plants here, by which the water consumers could tide over the summer.

An adequate supply for Uniontown must necessarily come from either Cheat River or Youghiogheny River, the use of ground water being out of the question. Assays of water from wells sunk to various depths at Fairchance and Dunbar show that ground water in this section is undesirable for public supply where surface waters can be had. Pumping from either river would involve considerable expense for pipe line and machinery. Cheat River would always furnish an adequate supply, as shown by the following table of flow: [a]

Estimated monthly discharge of Cheat River near Uneva, W. Va.

[Drainage area, 1,375 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches on drainage area.
1899.					
July			1,370	1.00	1.00
August	2,232	357	924	.67	.77
September	3,210	404	952	.69	.77
October	465	273	336	.24	.28
November	3,070	538	1,732	1.26	1.41
December	6,442	1,000	2,387	1.74	2.01
1900.					
July	4,610	730	1,888	1.37	1.58
August	1,956	273	614	.45	.52
September	730	190	254	.18	.20
October	730	190	340	.25	.29
November	3,070	273	903	.66	.59
December	7,270	1,136	2,682	1.95	2.03

Assuming that the number of people to be provided for is 50,000 and that the average consumption is 100 gallons a day, the amount needed would be 5,000,000 gallons a day. The foregoing table shows that the lowest actual flow recorded is 190 cubic feet per second in September, 1900. This would amount to 122,735,574 gallons a day, an amount sufficient to supply Uniontown many times over.

It would be well if Cheat River could be diverted for this purpose at such an elevation as to give a gravity supply, but such diversion is impracticable at a reasonable cost, as it would be necessary to take water out no nearer to Uniontown than Kingwood, a distance of about 40 miles, and as the river runs through a deep ravine it would be necessary to carry the pipe line downstream nearly to the Monongahela, doubling its cost. Another scheme involves pumping the water up several hundred feet before starting it across country in a

[a] Water-Sup. and Irr. Paper No. 75, U. S. Geol. Survey.

shorter pipe line. The former plan seems out of the question, owing to the great distance to be traversed and the consequent great expense; but if pumping is to be resorted to, it is not necessary to make the diversion at a point so far up the river. The topographic sheets issued by the U. S. Geological Survey show that the shorter line would begin near Cheathaven, where the elevation at the bank of the river is about 800 feet above sea level. The hill immediately southeast of Cheathaven rises to an elevation of about 1,130 feet, so that a reservoir on this hill could be filled by pumping about 330 feet. From Cheathaven the line would go 15 miles northeastward across the country, approximately parallel to the line of the Baltimore and Ohio Railroad. It can be kept below the 1,100-foot contour without tunneling except at two points—the first at Outcrop, where the line cuts through the ridge for 1,500 feet; the second about 4 miles from Uniontown, where a tunnel three-quarters of a mile long would have to be built through the rise at that point. The rest of the line seems to present no notable difficulties, the greater part of the town lying under the 1,000-foot contour.

If Cheat River were uncontaminated, the above would perhaps be the ideal plan, but in view of the figures as to typhoid fever at Point Marion, it is evident that this water would either have to be filtered or sedimented with great care. Sedimentation might not be completely efficacious, as is shown below, and if filtration is to be resorted to in addition to the pipe line the cost is prohibitive. The alternative seems to be to arrange for the use of filtered Youghiogheny water from Connellsville. It seems improbable that Indian Creek water from the new pipe line under construction by the American Pipe Manufacturing Company for private interests will be available for Uniontown. The work consists of a rubble masonry and concrete dam on Indian Creek about 4 miles upstream from the railroad station of that name. The dam is located just below the mouth of Mill Run, where the drainage area of the two streams is about 109 square miles. The structure impounds about 250,000,000 gallons. The 36-inch supply pipe runs down to the Baltimore and Ohio Railroad and follows it to Connellsville, where there is a 10,000,000-gallon distributing reservoir. From that point a 30-inch pipe goes to Everson and thence to Radebaugh Junction via County Home Junction. Thence it extends toward Pittsburg, its terminus not yet being decided on. There is a distributing reservoir at Hawkeye (capacity, 13,000,000 gallons), one at Youngwood (capacity, 1,000,000 gallons), and one at Radebaugh Junction (capacity, 8,500,000 gallons).

The water of Indian Creek, as will be seen later, is excellent. Extension of this line from Connellsville to Uniontown, if practicable, would solve the question of that city's water supply most satisfactorily, as the Indian Creek drainage basin could be patrolled at very little expense, there being little pollution on the banks of the stream.

Greensboro to Monongahela, Pa.—Between Greensboro and Monongahela a large and dense population takes its water unpurified from Monongahela River. Brownsville, which pumps the river water raw, is only 15 miles above Charleroi. Between these towns the river receives the sewage of Brownsville, with about 1,800 population; Bridgeport, with 2,000; West Brownsville, with about 1,000; California, 2,500; Coal Center, 1,000; Stockdale, 1,000; Fayette City, 2,000, and Bellevernon, 2,000, besides that of a number of smaller communities, aggregating not far from 15,000 people. Charleroi is drinking this dilute sewage raw. Its own population is about 7,000. Monessen, below it, has a population of about 2,500, and a dozen smaller places are scattered along the stream, so that at Monongahela the water contains the sewage from about 26,000 persons.

Typhoid fever mortality statistics for Charleroi are too meager to be of use. The few available for Monessen show a state of affairs such as might be expected. Every case visited by the medical inspector of Washington County in Monessen was traceable to the use of river water.

Typhoid mortality at Monessen, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1899	....	9	....
1900	30	50	10
1901	60	17	4
1902	75	....	9

Even if a number of these cases were foreign, conditions here are very bad. So high a percentage of mortality from typhoid fever means that the town has a highly contaminated water supply.

The conditions in all of these towns are bad; each one pumps its water supply from the stream raw and pours its sewage back into the stream for the next town below to pump into its mains. The sole protection of the consumers is the natural purification taking place in the river.

Monongahela, Pa.—At Monongahela, 10 miles below Charleroi, the supply is pumped from a filter well on the shore of the river, about 100 feet below low-water mark. The inefficiency of such a form of purification is shown on p. 55, and the water from the filter well here is so turbid as to show that it is coming from the river practically without change.

Field assays of water of Monongahela River at Brownsville and Monongahela and of public water at Uniontown, Pa.

[Parts per million.]

Determination	Monongahela River.		Public supply, Uniontown.
	Brownsville.	Monongahela.	
Turbidity	[a]10	[a]30	0
Color	180	250	5
Iron (Fe)	.5	1	0
Calcium (Ca)	46	44	0
Total hardness (as $CaCO_3$)	46.6	49	28
Alkalinity	27.6	24.9	14
Sulphates (SO_3)	31	38	0
Chlorides (Cl	9	6.5	9

[a] Estimated.

The sulphates shown in the Monongahela River assays are due to drainage from mines and wells along the stream, which contribute a little ferrous sulphate and at times a small quantity of free sulphuric acid. The extremely high color is also due in part to this cause, but chiefly results from the large amount of sewage in the stream, which makes it practically a septic tank. So far as mineral contents go, this is a very fair water for boiler purposes, the difficulty being with the varying amount of corrosive acid and sulphate appearing in the water at different times.

YOUGHIOGHENY RIVER BASIN.

The Youghiogheny does not carry so much water as the Cheat, but it is, nevertheless, a stream of great importance, because of the large population in its drainage area. Its source is in the mountains of Maryland, whence it flows northward as far as Confluence, where its principal tributary, Casselman River, enters. Up to this point the drainage area comprises only chiefly rural communities and the two small Maryland towns of Terra Alta and Oakland, the former with a population of about 800, the latter with about 1,000. A profile of the river is shown on Pl. III, page 30.

YOUGHIOGHENY RIVER ABOVE CASSELMAN RIVER.

Oakland, Md.—Oakland is built along Little Youghiogheny River, and drains directly into it. There is no public supply, most of the stores and some dwellings getting water from the large Offut wells, pumped by the principal merchants in the town. The water is too high in mineral content for industrial uses, for which the Youghiogheny water is much better.

Field assay of water from Oakland, Md.

[Parts per million.]

Determination.	Offut well.	235-foot well (B. and O).	Youghiogheny River 2 miles from town.
Turbidity	0	0	0
Color	5	31	81
Iron (Fe)	1.5	[a].8	1
Calcium (Ca)	88	0	0
Total hardness (as $CaCO_3$)	150	91	28
Alkalinity	35	97	(b)
Sulphates (SO_3)	49	[a]15	0
Chlorides (Cl)	39	39	9

[a] Estimated. [b] Water very faintly acid.

The Offut water, or quasi-public supply, is a typical hard well water from the rock. Its use for any purpose but drinking would lead to trouble, unless treatment were resorted to. The 235-foot well at the Oakland Hotel apparently contains considerable magnesium carbonate, the total hardness being high, with calcium too small to be determined by field methods. The identical chlorine content is interesting.

The Youghiogheny water is very pure and soft, but even up here near the source of the stream the acid of the mine wastes is determinable.

Terra Alta, Md.—Terra Alta has a supply of a similar nature, derived from a deep well at the planing mill. The water seems too high in incrusting solids to be best for boiler use. A very good city supply could be drawn from Terra Alta Lake, about 2 miles from the town, a body of water covering several acres, whose shores could be patrolled very easily. This lake, as well as Snowy Creek, drains into the Youghiogheny, which carries more or less drainage from adjacent farms. Analysis of the waters of the lake and creek are given below.

Field assays of water from Terra Alta, Md.

[Parts per million.]

Determinations.	Public supply 100-foot well.	Terra Alta Lake.	Snowy Creek.
Turbidity	0	0	0
Color	20	122	40
Iron (Fe)	2	1	1
Calcium (Ca)	116	0	0
Total hardness (as $CaCO_3$)	90	21	21
Alkalinity	44	17	19
Sulphates (SO_3)	[a]10	0	0
Chlorides (Cl)	14	14	9

[a] Estimated.

The public supply is at present piped to but twelve places, but the quantity of water is sufficient for many more. The two surface waters would undoubtedly be better, however, on account of their softness, if suitable measures could be enforced to keep pollution out of them. The high color of the lake water is probably due to vegetable matter in solution, the drainage area being well covered, The creek is a very small stream, flowing little water in the summer, so that storage would be necessary if it were used for public supply.

Addison and Somerfield, Pa.—From Terra Alta to Confluence, a distance of nearly 40 miles, the population is very scanty, the chief pollution of the stream being from mine waters. Several small villages drain into the main stream, the most important being Addison and Somerfield. At neither place is there a public supply, water being obtained from individual wells. Addison is about 4 miles from the river and has a population of about 300, that of Somerfield being the same.

Field assays of water from Addison and Somerfield, Pa.

[Parts per million.]

Determination.	20-foot well, Addison.	52-foot well, Somerfield.	Youghiogheny River at Somerfield.
Turbidity	0	0	0
Color	17	74	45
Iron (Fe)	0	2.5	(a)
Calcium (Ca)	130	88	0
Total hardness (as $CaCO_3$)	139+	139+	35
Alkalinity	45	95	15
Sulphates (SO_3)	25	15	0
Chlorides (Cl)	70	9	9

a Slight trace.

Both these wells furnish typical hard rock water, unsuitable for laundry or boiler uses, in quantity too small to be of importance except for private supplies. The sample of river water analyzed was taken below the National Pike bridge, about 100 yards below the mouth of a small creek. The acidity found at Oakland is not present at this point, the mineral contents of the stream being precisely similar to those of the West Virginia mountain stream waters and of the spring waters considered below. The alkalinity is important in connection with the later discussion of the germicidal influence of acid drainage, as it shows that the influence of the acid does not extend far.

CASSELMAN RIVER.

Casselman River, a typical mountain stream with an exceedingly swift current, drains a great deal of coal country, so that its waters are nearly always stained a bright yellow with mine drainage. The drainage area is not densely populated, but along the course of the stream there are many little villages and coal-mining camps, so that in the aggregate the drainage is a serious factor. The water supplies of the small communities at the headwaters are all derived from springs, though many people use individual wells.

Field assays of waters in upper Casselman River basin.

[Parts per million.]

Determination.	Elk Lick well.	Elk Lick Spring.	Boynton Spring.	Flaugherty Creek at Keystone Junction.
Turbidity	0	0	0	0
Color	45	5	22	36
Iron (Fe)	(a)	0	Trace.	(a)
Calcium (Ca)	92	0	0	0
Total hardness (as $CaCO_3$)	132	49	35	35
Alkalinity	68	11	12	16
Sulphates (SO_3)	0	0	0	0
Chlorides (Cl)	19	19	14	9

a Slight trace.

Flaugherty Creek at Keystone Junction, Pa.—Flaugherty Creek, which enters Casselman River at Keystone Junction, above Meyersdale, presents a typical normal water of this section, soft and pure. It is a very rapid little stream, draining an area having but little population. Nearly all the inhabitants, however, chiefly coal miners, are collected along the creek, and all their wastes go into the stream sooner or later. This section is rich in springs of the type shown, and a group of these may yield enough water to supply 2,000 or 3,000 people, as at Meyersdale.

Meyersdale, Pa.—This town, with a population of about 3,000, has a gravity supply from a spring-fed reservoir in the hills about 5 miles distant. The water is piped to near-by hamlets, supplying in all about 4,000 people, and until recently, in seasons of drought, proved sufficient in quantity. It is probably as free from contained solids as any natural water.

Field assays of waters from Meyersdale, Pa.

[Parts per million.]

Determination.	Public supply at Meyersdale.	Casselman River 3 miles south of Meyersdale.
Turbidity	0	a 2
Color	5	122
Iron (Fe)	0	a 5
Calcium (Ca)	0	0
Total hardness (as $CaCO_3$)	14	91
Alkalinity	6	7
Sulphates (SO_3)	0	a 20
Chlorides (Cl)	9	19

a Estimated.

It is evident from several points in the assay that Casselman River receives much mine drainage up to this point. The lack of calcium would indicate the presence of magnesium, the alkalinity being so low as to make the presence of any great quantity of alkaline carbonates improbable. The low alkalinity and the trace of sulphates point to the partial neutralization of the alkalinity of the unpolluted water by ferrous sulphate and free sulphuric acid from the mines. The small iron content indicates that the sulphate pollution results principally from free acid.

Meyersdale to Confluence, Pa.—Between Myersdale and Confluence are several small villages, none having public supplies but Berlin and Garrett. The analyses subjoined show that the quality of normal waters here is excellent. They are characteristic of this section.

Field assays of waters collected between Meyersdale and Confluence, Pa.

[Parts per million.]

Determination.	Laurel Creek near Hays Mill.	Public supply, Garrett (spring.)	Public supply, Berlin (spring.)	Spring at Markleton.	Spring at Ursina.	18-foot well at Casselman.	20-foot well at Beachdale.	20-foot well at Rockwood.	Coxes Creek at Rockwood.
Turbidity	0	Slight.	0	0	0	0	0	0	([a])
Color	45	122	22	5	22	22	17	5	113
Iron (Fe)	Trace.	0	([b])	0	0	0	([b])	0	0
Calcium (Ca)	0	0	0	0	70	107	38	162	15
Total hardness (as $CaCO_3$)	35	42	28	35	132	139	97	160	35
Alkalinity	20	17	15	13	80	28.5	44	29	14
Sulphates (SO_3)	0	0	0	0	20	63	([b])	41	[a]5
Chlorides (Cl)	9	9	9	14	14	49	19	181	12

[a] Decided. [b] Estimated. [c] Very slight trace.

The first five analyses show normal spring waters of excellent quality for all industrial purposes. The high color of the Garrett water is probably due to a foul condition of the reservoir, for the town comprises only a few hundred people and the supply is left to take care of itself to some degree. The well waters are too hard to be of use for anything but drinking. Beachdale is a mere handful of coal-miners' huts and a few farm houses, and Rockwood is a village of about 400, with no public supply. The Baltimore and Ohio Railroad Company pumps Casselman River water to its tank at Rockwood for boiler uses, supplying it to a hotel also. The assay of the shallow well at this point shows the nearness of the rock to the surface, the chlorides in particular being unusually high. None of these supplies are important for anything but private uses, except perhaps Coxes Creek, which enters the Casselman at Rockwood. This is a fine stream, flowing through a lumber country, chips and sawdust in quantity polluting the water. The spring at Markleton is piped to the sanitarium at that point, supplying several hundred persons in the summer. The Ursina spring fills a 1-inch iron pipe, gushing out under a strong head. Casselman is a hamlet of a few dozen families, all water supplies being either springs like those noted or individual wells.

Confluence, Pa.—This town, which stands at the confluence of Laurel Creek, Casselman River, and the Youghiogheny, formerly used Laurel Creek as a source of water supply. The pollution from coal mines along this creek, however, became so great that a new source of supply was found in Drakes Run, an exceptionally pure mountain water (see assay on p. 49) rising in practically uninhabited country and flowing through a sparsley populated farming section. The town has about 1,500 people, with a very large tannery located on the river. The town sewage as well as the tannery refuse all go directly into the stream.

The notable thing about the river assay at this point (see p. 49) is the nearly complete disappearance of the mine drainage, the only traces left being the iron content and the comparatively low alkalinity, showing that the acid wastes are not considerable enough to keep the water acid more than a short distance below the points where mine drainage enters.

YOUGHIOGHENY RIVER BELOW CASSELMAN RIVER.

There is no town of over a few hundred population between Confluence and Connellsville. The water supply between these points is derived entirely from individual wells, such as those at Ohiopyle, which are not important except as private supplies (see assays on p. 49). The water of the 50-foot well at Ohiopyle probably contains some magnesium carbonate,

with iron probably present as a carbonate also. The other well shows a remarkably low alkalinity, considering its hardness, perhaps due to the carbonates being almost entirely those of the incrusting solids. The deeper well penetrates the sandstone, the shallower one only touching the top of the rock.

Indian Creek, Pa.—At Indian Creek station the Youghiogheny receives its large tributary of that name, a very beautiful and relatively unpolluted stream with a watershed comprising about 125 square miles. This creek was seriously considered for Pittsburg's water supply by a gravity system, the quality of the water being excellent. The report of Mr. Kuichling on the plan showed an estimated first cost of about $13,000,000 for storage reservoir, pipe lines, etc., as compared with $2,000,000 or $3,000,000 for a filtration plant.

Field assays of waters from Confluence, Ohiopyle, and Indian Creek.

[Parts per million.]

Determination.	Confluence.		Ohiopyle.		Indian Creek.
	City supply, Drakes Run.	Casselman River.	50-foot well on north bank of river.	19-foot well on south bank of river.	
Turbidity	0	0	0	0	0
Color	27	45	0	5	17
Iron	0	1	10	0	0
Calcium	0	0	0	57	0
Total hardness	21	32	132	132	28
Alkalinity	14	9	50	10	13
Sulphates	0	(a)	[b]10	15	0
Chlorides	9	9	17	44	9

[a] Slight trace. [b] Estimated.

This assay shows that Indian Creek is a spring stream carrying pure water like the normal waters shown above.

The only available measurement of the Youghiogheny near this point is that made during the drought of October, 1892, by Kenneth Allen, for the Frick interests, showing a flow of 106 cubic feet per second. By taking the October flow of Indian Creek at 15 feet, it may therefore be said that the Youghiogheny at the very driest time carries not less than about 120 cubic feet per second, while during floods it may carry 2,500 cubic feet per second.

Connellsville, Pa.—Connellsville, a city of perhaps 9,000 people, is about 28 miles below Confluence. Its water supply is pumped from Youghiogheny River for filtration in mechanical filters of the Pittsburg type. The plant seems to be efficiently operated, but there is more or less local dissatisfaction with the quality of the water, which contains a strong trace of mine drainage. The only remedy for this condition is a new source of supply. The new pipe line from Indian Creek, mentioned above, may remove the objection.

Typhoid-fever statistics are not available for any of the towns of this section except Connellsville, and even there only for a few years. In 1894, when the population was 5,629, there were 3 cases and 1 death reported in Connellsville from typhoid fever; in 1895 there were 5 deaths from this cause; in 1897, out of a total mortality of 71, there was 1 death from typhoid, with 6 cases; in 1898 there were 5 deaths in a total mortality of 104, or 4.8 per cent. These figures are too meager to be of much value except to show the probable presence of typhoid bacilli in Connellsville sewage, which finds its way into the Youghiogheny.

A sample of the city water was taken from a hotel tap, and its assay (p. 50) shows that the mineral impurities in the river have greatly increased. The lack of iron and the small trace of sulphates indicate that very little mine drainage enters the stream here.

On account of the use of coagulant in the filters it is likely that the raw river water is a little softer.

From this point down to Pittsburg the population is dense, towns of from a few hundred to a thousand people dotting either shore closely. The sewage and drainage from all these places goes into the stream, making it practically a sewer. Ground waters are of poor quality a little distance away from the stream, as is shown by the field assay (below) at Dunbar, which has no public supply, though the population is about a thousand. This is a very hard water, and none of the wells give a very abundant supply. This town could very well take water from the Connellsville-Uniontown pipe line suggested above. It drains into the Youghiogheny above West Newton.

West Newton, Pa.—West Newton (population about 2,500), 15 miles below Connellsville, uses well water as a city supply, the wells being owned by private parties. The wells are 190 feet deep, pumping to a tank, whence the taps are supplied by gravity. The water is higher in color than it should be for a deep ground water, owing probably to fouling in the tank or in the pipes. A field assay of the water is given below.

This is a remarkably soft water, considering the depth from which it comes. It would not be suitable for steam making, the high chlorides being very corrosive. Its softness and high alkalinity indicate the presence of carbonates and chlorides of the alkalies in large quantity.

If care is used in casing the wells this supply should be very fair for drinking and domestic uses.

The few typhoid-fever statistics available for this town indicate that many of its people are drinking water from individual wells.

Typhoid mortality at West Newton, Pa.

	Total deaths.	Typhoid cases.	Typhoid deaths.
1895		4	4
1897			4
1900	30		3

It is evident that West Newton also is a contributor of typhoid drainage to Youghiogheny River.

McKeesport, Pa.—The largest city on the Youghiogheny is McKeesport, with an estimated population in 1904 of 37,000. The city water supply is the worst on the Youghiogheny watershed. It is a mixture of two waters—raw water from the river and well water from wells about 40 feet deep. The field assay herewith shows the quality of the mixture:

Field assays of waters from West Newton, Dunbar, Connellsville, and McKeesport.

[Parts per million.]

Determination.	West Newton, 190-foot wells.	Dunbar, 117-foot wells.	Youghiogheny River.	
			Connellsville.	McKeesport.
Turbidity	0	0	0	(a)
Color	78	17	22	54
Iron (Fe)	0	Trace.	0	2
Calcium (Ca)	38	119	67	126
Total hardness (as $CaCO_3$)	42	139	56	95
Alkalinity	340	132	22	48.5
Sulphates (SO_3)		59	[b] 5	108
Chlorides (Cl)	132.3	29	9	9.8

[a] Slightly cloudy. [b] Estimated.

The dilution of the river water by the pure ground water is insignificant so far as the healthfulness of the supply is concerned, the mixture being analogous to seeding a pure water with sewage bactéria, a process that produces conditions under which, as is well known, the organisms will grow faster for a time than in foul water. When it is remembered that in many of the towns along the stream there is always some typhoid fever, and that there is some at some time in all, it is difficult to understand how an American community can drink such disease-polluted water. Furthermore, the river valley for 10 or 15 miles immediately above McKeesport is thickly populated, and small hamlets along the stream have outhouses along the banks, so that a trip up the river from McKeesport ought to convince the most skeptical, by the evidence of their eyes, of the polluted character of the supply. These facts can fortunately be supplemented by figures showing typhoid mortality at McKeesport for many years.

Typhoid mortality at McKeesport, Pa.

Year.	Population.	Total deaths.	Typhoid cases.	Typhoid deaths.	
				Number.	Rate per 100,000.
1893	....	464	123	....	....
1894	....	454	63	8	....
1895	....	444	299	29	....
1896	....	537	144	13	....
1897	....	468	86	8	....
1898	....	528	100	15	43.8
1899	....	589	151	14	40.9
1900	34,227	684	315	23	67.3
1901	35,576	693	275	29	81.5
1902	36,925	799	262	30	81.2
1903	38,274	788	313	43	112.3
1904	....	796	324	48	....

It is noteworthy that 162 of the total number of deaths for 1904 from violent causes were over 20 per cent. If this ratio were not so high the typhoid percentage mortality would be even more serious.

In 1904 the death rate from typhoid fever in McKeesport was 129 per 100,000 of population, or 6 per cent of the total mortality. This figure is enormously high, placing McKeesport in the same class with Allegheny and Pittsburg as a hotbed of water-borne disease. Even in the city of Washington, which is popularly thought to be a center of this disease, the number of deaths per 100,000 in 1904 was only 47, yet the situation there was considered so grave as to necessitate the erection of a filtration plant. McKeesport, like Pittsburg and Allegheny, is in the condition of having a continuous epidemic of typhoid fever. The highest death rate from this disease in Lowell, Mass., before the change from a polluted river supply to ground water, was 112 in 100,000 from 1886 to 1890, inclusive. The highest recorded typhoid-fever death rate for Indianapolis was 101 per 100,000 in 1895. This has been lowered year by year to 56 per 100,000 in 1903, which is considered so high as to necessitate a change in the source of supply. Pittsburg, whose water supply from Monongahela and Allegheny rivers has for years been unspeakably bad, had 144 deaths per 100,000 in 1900, 125 in 1901, 144 in 1902, and 139 in 1903. Grand Rapids, Mich., which has been very seriously considering the question of a purer water supply than its present one, has from 31 to 51 deaths from typhoid fever per 100,000 for the years 1899 to 1903, inclusive. It is evident that McKeesport is supplied with water that is dangerous and in no sense potable or fit for consumption by human beings. The ground-water supply should be so extended as to furnish sufficient for the needs of the town, or, if this extension is impracticable, Youghiogheny water should be filtered. Analyses of Youghiogheny River water made by Pittsburg engineers are relied upon by the city officials to prove its potability. The degree of confidence

which may be placed in them may be shown by a comparison of the dates of collection and analysis. The samples were collected January 19, February 3 and 16, and March 3 and 31, 1903. The secretary of the local board of health states over his signature that the analyses were made "about April and May." Therefore all the determinations, except as to inorganic constituents, are worthless, for the conditions under which the samples were kept determined whether the organisms would increase or die out. There may have been, and probably were, thousands of bacteria in the samples when they were collected. By the time the samples were analyzed, a few days to a few weeks after collection, the food content of the medium may have been exhausted and the organisms very naturally died. If the samples had been kept a little longer there would probably have been no bacteria at all left in them. To be of value bacteria determinations should be made within six hours after collection of the samples.

The principal claim made for the water is the fact that it contains so much iron and sulphuric acid as to make it germicidal to bacteria. The purifying action of the iron sulphate is discussed in detail under the heading "Self-Purification" on pages 69-73. In August, 1905 (see field assay), there were but 2 parts per million of iron in the sample taken, although the analyses of the river water referred to show 12 to 44 parts per million. Evidently, as in the Monongahela water, the coagulating action of the ferrous sulphate could not be relied upon to go on regularly, on account of the variation in the amount of iron, which sometimes went far below the required quantity.

MONONGAHELA RIVER BELOW YOUGHIOGHENY RIVER.

Below McKeesport Monongahela River is lined on both banks with little towns, two of which, Braddock and Homestead, have a population exceeding 15,000. Although these two are the only large towns along the river, there are so many smaller ones that the banks present an almost continuous succession of dwellings and mills. All of these drain into the river, some of them by modern sewers. The drainage of a number of towns in Westmoreland County, chief among which is Greensburg, also finds its way into the stream through small tributaries, although in comparison with the direct pollution by the towns noted above, those away from the river are negligible so far as sewage is concerned.

Greensburg, Pa.—Greensburg (population 6,500) has a gravity supply from a system of impounding reservoirs on Chestnut Ridge and Dry Ridge, having a capacity of 75,000,000 gallons, the daily consumption being from 1,700,000 to 2,000,000 gallons. The supply is similar in quality to that of Bradford and Kane, being typical mountain spring water. An effort is made here to assure safety from pollution by sanitary inspection of the watershed. The company owns 1,200 acres of land on the two main drainage areas, covering nearly all the watershed drawn upon, and cooperates with the monastery of St. Vincent, which owns one-third of the entire watershed, in guarding the drainage area. All dwellings and farm buildings have been cleared off and an arrangement has been made with farmers having holdings around the drainage area whereby they are furnished constable's badges and are paid $10 a year to warn trespassers off the land. This plan seems to work well and has helped to crystallize public opinion in favor of a pure supply. The company claims to be supplying about 30,000 people all told, including Greensburg, Derry, Jeanette, Youngwood, and Lycippus.

Field assay of Greensburg water.

[Parts per million.]

Determination.		Determination.		Determination.	
Turbidity	0	Color	35	Iron	(a)
Calcium		Total hardness	22	Alkalinity	22
Sulphates	0	Chlorides	6		

a Very slight trace.

Typhoid-fever statistics for Greensburg are too meager to be of use.

Braddock, Pa.—Many of the towns along the banks of the Monongahela use water from driven wells. Others, like Braddock, pump the river water raw. The danger is at this point somewhat disguised by "natural filtration" through a covered well 20 by 20 feet, situated about 30 feet from the river. A drilled well about 40 feet deep in the bottom of the large one is drawn on at the same time. From the facts already stated it is evident that the purity of the well water will by no means diminish the toxicity of the river water. The work of Frankland and Klein shows that disease germs may live longer in unpolluted well water than in surface water. The inefficiency of this form of filtration has already been shown (p. 54 et seq). It should be abandoned, either for ground water or proper sand filtration.

The only statistics at hand to show typhoid-fever mortality at Braddock are for 1900, when, in a population of 15,654, there were 10 deaths from this disease, representing probably 100 cases, enough to show that in that year, and probably in others, typhoid fever was prevalent in the town to a dangerous extent.

Homestead, Pa.—With regard to the other towns on Monongahela River above Pittsburg, the facts are similar as to what they take from the river and what they put back into it. The largest is Homestead, with about 15,000 inhabitants, which, after years of costly experience with typhoid fever resulting from drinking raw river water, is filtering Monongahela River water for its public supply. Its own sewage, however, still pours into the stream for the next town below to drink.

SUMMARY OF CONDITIONS IN MONONGAHELA RIVER BASIN.

The discussion of conditions on the Monongahela above McKeesport has shown the dangerous character of the water of that stream for drinking purposes; the discussion of Youghiogheny River drainage shows the existence, at all points along its course where typhoid statistics are obtainable, of sewage pollution containing the germs of water-borne disease. The smaller stream flow of the Youghiogheny makes dilution of the contamination to any great degree impossible, and its high rate of flow over most of its course puts detention out of the question until West Newton is reached, coincidently with a great increase in the number of centers of population. From Oakland to West Newton, a distance of approximately 80 miles, the river falls 1,591 feet, with a slope of nearly 20 feet to the mile. The discussion of the Allegheny and Monongahela drainage areas has been sufficient to show that the stream flow through this mountain country, with a fall of 3½ feet to the mile, is too rapid to permit effective sedimentation, and it is clear that the high grade of the Youghiogheny River channel puts purification by detention out of the question. Casselman River, carrying the sewage of Meyersdale, has a fall of about 600 feet in about 30 miles, making, roughly, a fall of 20 feet to the mile. It seems evident that the sewage of Meyersdale, Confluence, and Connellsville are practically unpurified when they come down to West Newton. On page 67 it is shown that self-purification of Illinois River is not complete within 100 miles of the source of the pollution. With a slope about seven times as great, the Youghiogheny above McKeesport is expected to perfectly purify, by one agency or another, the sewage of about 20,000 people, in a stream flowing sometimes only about 125 cubic feet of water per second, or, roughly, 7,500 cubic feet per minute; while below McKeesport, with a very low slope, there is a population of approximately 100,000 to take care of with about the same amount of water. What chance is there for complete self-purification in Youghiogheny River in the 15 miles intervening between West Newton and McKeesport?

It has been shown in the discussion of the Cheat River drainage that even so comparatively unpolluted a stream may and does carry typhoid bacilli down from remote and small sources of pollution to breed disease in a large proportion of the population drinking the water.

In no way can the conclusion be escaped that water from Youghiogheny River used raw is in a high degree dangerous to public health. The claim made with respect to the germicidal influence of mine drainage results from a misapprehension of the action of such drainage. Though this water occasionally carries much free acid, the purifying action, such as

it is, results principally from the sedimentation which goes on through the coagulating properties of the calcium in the water and the ferrous sulphate coming from the mines. This action is fully discussed on pages 65-73, it being shown that even when most efficient, under the most favorable and well-controlled conditions, such purification is not sufficient by itself to make a water supply reasonably safe. Finally, if the mine drainage did actually operate to free the water of pathogenic organisms, the typhoid-fever death rate at McKeesport, where this water is drunk freely without purification, ought to show the effect of such purification. On the contrary, as the figures given above show, the condition there is extremely bad and the death rate from typhoid fever is going up.

The foregoing discussion of the Monongahela watershed shows that its waters are as badly contaminated and as unfit for drinking as those of the Allegheny.

AGENCIES COMMONLY SUPPOSED TO COUNTERACT THE EFFECTS OF POLLUTION.

NATURAL FILTRATION.

GENERAL STATEMENT.

There is a strong popular belief that a polluted river water will purify itself in a flow of from 7 to 30 miles. It need hardly be said that this is not true. Sedimentation, the chief factor in the self-purification of natural waters, goes on more rapidly in standing than in running water. Many cities which take water from running streams upon whose drainage areas typhoid fever is prevalent have been visited by epidemics of the disease. The historical Plymouth, Pa., epidemic, the Mohawk Valley epidemic of 1891, the Lowell-Lawrence epidemic of 1891, all show that a stream polluted with typhoid sewage retains toxic material for a long time.

Experiments made with the typhoid-fever organism have shown that it is able at times to retain its vitality in potable waters for weeks and months. Even if pollution at any particular point should be intermittent, the polluted water might contain the bacilli of disease, and its use for drinking purposes is therefore attended at all times with uncertainty and danger. The great majority of towns situated on running streams draw their supplies from those streams in too many cases without purification of the water.

> The delivery to the people of unpurified water is nowadays regarded everywhere as extremely dangerous, as such water has too often been found to be a fruitful source of typhoid fever and kindred diseases. There is not a town in the eastern United States taking its water unpurified from a large stream which has not either an abnormal typhoid mortality rate or has been visited by a typhoid epidemic.[a]

In modern practice it is an axiom that raw surface water is safe as a city supply only when the entire drainage area of the stream used is subjected to rigid sanitary control. "All surface waters must be considered dangerous, and their use in the raw state for a general supply in each particular case either has been, is now, or is likely to be the cause of disease and death,"[b] except when properly guarded, when they have no superior as water supplies. New York City's water supply is impounded from the run-off of a large drainage area from which whole villages have been removed, the entire area being cleared of habitation. The typhoid-fever death rate of New York City is very low.

The plan of natural filtration, by causing the polluted waters of a running stream to seep through the sand and gravel of its own bed, was for a long time considered adequate purification; the annual decimation by typhoid fever in towns so supplied has demonstrated the ineffectiveness of the plan in its three best-known forms. These are, first, filter wells, with permeable bottom and sides, such as are used at Monongahela, Braddock, and many West Virginia towns; second, filter galleries, such as those of Lowell, Mass., before 1891, and Columbus, Ohio, at the present day; third, filter cribs, in extensive use all over the country, and particularly in the vicinity of Pittsburg.

Reliable data as to the efficiency of filter wells are not available. Filter galleries and cribs, however, have long been in use in places where continuous analyses and fairly accu-

[a] Sedgwick, W. T., Test, Chicago Drainage Canal Com., vol. 3.
[b] Kemna, Dr. Adolph. Trans. Am. Soc. Civil Eng., vol. 54, Pt. D, p. 157.

rate statistics of typhoid mortality have been kept, making it possible to determine with accuracy what effect natural filtration has on the quality of polluted surface waters.

A very important distinction must be made between galleries and cribs. Cribs are invariably located in the beds of more or less polluted streams, the waters of which seep through the superincumbent sand into the interior of the structure and are pumped into the city mains. Water so obtained is, therefore, practically surface water, the only purification being produced by its passage through a few feet of sand and gravel. Filter galleries, however, being excavated in the river bank, are in a position to impound ground water on its way to the stream, besides allowing the seepage of surface water from the river. The experience of communities using such supplies goes to show that bacterial purity of the supply is directly proportional to the ratio between the ground water and the river water in the gallery, as will be evident from facts presented below. Properly speaking, therefore, galleries do not effect filtration of contaminated water, being successful only when the contaminated water has no access to them, paradoxical as that may seem. This point should be kept in mind in accounting for the wide discrepancies in the bacterial content of water treated by natural-filtration schemes in various towns.

FILTER GALLERIES.

Woburn, Mass.—At Woburn, Mass. (population 4,000), the supply is taken from so-called filter galleries impounding ground waters on their way to Horn Pond, which has a drainage area of 7¼ square miles and a surface of 103 acres. Prior to 1899, when the galleries were installed, the typhoid mortality rate was high, as may be seen from the figures below:

Deaths per 100,000 from typhoid fever at Woburn, Mass.

Years.	Deaths.	Years.	Deaths.
1871-1875	57	1891-1895	48
1876-1880	20	1896-1900	13
1881-1885	25	1901-1903	2
1886-1890	38		

Although conditions did not immediately improve after 1889, the remarkable reduction between 1891 and 1903, bringing the death rate from this cause down to only 2 per 100,000, shows conclusively that the galleries are supplying good water. That this is ground water on its way to the pond, and therefore more thoroughly purified than river water can ordinarily be, is shown by the experience of Lowell, Mass.

Lowell, Mass.—Prior to 1891 Lowell took its public supply from filter galleries near the Merrimac River. The figures showing typhoid death rate are as follows:

Deaths per 100,000 from typhoid fever at Lowell, Mass.

Year.	Deaths.	Year.	Deaths.
1871-1875	98	1891-1895	73
1876-1880	43	1896-1900	25
1881-1885	79	1900-1903	20
1886-1890	112		

Prior to the abandonment of the galleries in 1891 and the substitution of deep wells for the supply the death rate at Lowell from typhoid fever was steadily increasing. The steady decrease in the number of deaths since the wells were put in service indicates the badly polluted condition of the former filtrate from Merrimac River.

The striking difference in results in these two cases, and the fact that no less than 20 towns in Massachusetts get their supplies wholly or in part from filter galleries or similar

devices, mostly with good effect, shows that a filter gallery is inadequate to purify contaminated river water for drinking. The filtration only clears the water of visible impurities, frequently making it doubly dangerous by masking the pollution. The device, when successful, is merely a form of well that has a much greater collecting surface than an ordinary well can have, collecting ground water in the same way as an ordinary shallow well and subject to the same contamination from accidental pollution. When unsuccessful, it is nothing but a device for straining out turbidity and visible impurities in polluted river water, frequently making it clear and inviting in appearance, when in fact it is dangerously charged with the germs of water-borne disease. A few cases are cited below in support of this statement, out of the many instances on record.

Indianapolis, Ind.—In Indianapolis, Ind., the number of deaths from typhoid fever per 100,000 is given by Mr. Fuller in his report on the supply as follows:

Deaths per 100,000 from typhoid fever at Indianapolis, Ind., 1895–1904.

Year.	Deaths.	Year.	Deaths.
1895	101	1900	47
1896	56	1901	36
1897	43	1902	48
1898	42	1903	56
1899	46	1904	82

As a death rate from this disease of over 20 per 100,000 is generally considered sufficient to justify a serious investigation of the source of infection, it is evident that the figures given put Indianapolis in the class of cities with notoriously bad water supplies. The supply is derived from filter galleries about to be abandoned.

Columbus, Ohio.—Similar conditions have existed at Columbus, although the figures are not nearly so high. In the United States there are so many towns with typhoid death rates as high as those of Pittsburg, with 132, and Allegheny, with 129, that the significance of the figures at Columbus is not appreciated as it should be.

Deaths per 100,000 from typhoid fever at Columbus, Ohio, 1898–1903.

Year.	Deaths.	Year.	Deaths.
1898	28	1901	36
1899	23	1902	37
1900	42	1903	34

The supply is partly from filter galleries about to be abandoned.

Findlay, Ohio.—Findlay, Ohio, formerly took part of its water supply from filter galleries in Blanchard River, also pumping directly from that stream.

Typhoid mortality at Findlay, Ohio, 1897–1903.

Year.	Population.[a]	Deaths.	Rate per 100,000.
1897	16,000	8	50
1898	16,500	2	12
1899	17,000	10	59
1900	17,613	16	91
1901	18,000	6	31
1902	18,500	7	38
1903	19,000	5	26

[a] Estimated, except for 1900.

The figures for 1899 and 1900 show a general infection, indicating a polluted water supply

Springfield, Ohio.—In Springfield, Ohio, with a population of 38,253 in 1900, and a supply in part from filter galleries of this kind, the typhoid fever death rate has been as follows:

Deaths per 100,000 from typhoid fever at Springfield, Ohio, 1898–1903.

Year.	Deaths.	Year.	Deaths.
1898	24	1901	20
1899	64	1902	51
1900	44	1903	42

Plainly this is contaminated surface water.

Grand Rapids, Mich.—In Grand Rapids, Mich., where water is taken from three filter galleries beneath the river bed, the mortality as shown in the table is too high.

Deaths per 100,000 from typhoid fever at Grand Rapids, Mich.

Year.	Deaths.	Year.	Deaths.
1898	34	1901	35
1899	31	1902	51
1900	42	1903	35

These galleries were installed in 1890, the raw Grand River water being pumped before then. The death rate since has risen.

Summary.—The evidence shows that filter galleries have no bacterial efficiency, and that these to be successful must be so constructed as to impound ground water only.

FILTER CRIBS.

Tarentum, Pa.—At Tarentum (population 7,000), about 19 miles above Pittsburg, a crib in Allegheny River, designed by Messrs. Chapin and Knowles, is the only means of purification at hand. The sample taken shows such high turbidity as to make it evident that the crib is out of commission, probably having been damaged by the spring freshets.

Field assay of water from Allegheny River at Tarentum.

[Parts per million.]

Determination.		Determination.		Determination.	
Turbidity	[a]30	Color	180	Chlorides	24.5
Calcium (Ca)	66	Total hardness (as $CaCO_3$)	51.4	Iron (Fe)	4 +
Sulphates (SO_3)	33			Alkalinity	41

[a] Estimated.

The statistics of deaths from typhoid fever at Tarentum are too few to justify conclusions as regards the supply. In 1896 there were 48 cases; in 1897 there were 27 cases, 2 dying; in 1898 there was 1 death from this disease.

Montrose, near Brilliant, Pa.—The figures below show the results of analyses of Allegheny River water before and after it had passed through the Montrose crib, 4 miles above Brilliant, which furnishes also a portion of Allegheny's water supply.

Analyses showing efficiency of Montrose crib, near Brilliant, Pa.

[Parts per million.]

Date.	Water analyzed.	Turbidity.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Bacteria per c.c.
1897.								
July 28	River water, raw	Muddy	0.310	0.034	None.	1.036	9.1	9,150
	Effluent from crib	Muddy	.315	.046	None.	1.165	10.2	9,200
Aug. 9	River water, raw	Slight	.197	.011	None.	.888	12.0	700
	Effluent from crib	Slight	.250	.027	None.	.666	14.0	725
Aug. 16	River water, raw	Very turbid	.340	.060	None	.750	47.0	2,225
	Effluent from crib	Decided	.174	.050	None.	.375	15.0	15,050
Aug. 23	River water, raw	Slight	.190	.020	None.	.750	12.4	3,050
	Effluent from crib	Slight	.195	.020	None.	.525	13.0	2,575
Aug. 30	River water, raw	Decided	.190	.028	None.	1.200	18.6	4,550
	Effluent from crib	Slight	.175	.018	None.	.750	17.5	10,050
Sept. 7	River water, raw	Slight	.140	.024	None.	.600	20.9	15,050
	Effluent from crib	Slight	.176	.032	None.	.675	21.5	17,500
Sept. 22	River water, raw	Very slight	.122	.014	None.	.712	10.8	2,250
	Effluent from crib	Very slight	.180	.034	None.	.300	29.6	2,425

It has already been shown that typhoid fever is constantly present in severe form at nearly every important town on the watershed of the Allegheny, and the sewage from these towns unquestionably carries disease-producing bacilli into the river. The efficiency of any plant for purifying the river water may therefore be rated by its effect on the bacterial content.

Inspection of the above figures, bracketed together to permit convenient comparison of analyses made on the same day, shows that the effluent water usually contains many more organisms than the raw water and never appreciably less. Average analyses of the effluent water, each representing the average results for one month, follow:

Average analyses of effluent water at Montrose crib, near Brilliant, Pa.

[Parts per million.]

Date.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Bacteria per c. c.
1897.						
October	0.128	0.014	None.	0.637	30.0	97,262
November	.135	.020	None.	.731	33.0	29,250
December	.090	.017	None.	.975	46.7	27,000
1898.						
January	.090	.045	None.	.637	119.4	30,400
February 16	.058	.028	None.	1.125	231.0	13,900
March	.076	.024	None.	5.000	257.5	7,967
April	.070	.024	None.	.675	120.5	7,850
May	.099	.042	None.	.300	110.0	7,600
June	.126	.026	None.	.225	51.5	43,000
July	.094	.017	None.	.975	24.1	19,300
August	.111	.025	None.	.562	41.8	21,000

Not one of these effluents can be truthfully called a filtered and safe water, and it is evident that so far as bacterial purification is concerned the crib might as well not be there. The crib is of approved form, about 2,500 feet long, 32 feet wide, and 7 feet deep, its framework having been built of 6 by 8 hemlock timbers, laid flat. The timbers are spread by blocks

4 inches thick, spaced about 3 feet apart. It is tightly planked over on top with 3-inch planks, but its sides and bottom are open. In placing the crib an excavation somewhat larger than the area of the structure was made and the crib was floated over and sunk into place. It is covered with stones and coarse gravel with sand upon top. The average depth of gravel and sand on the crib is 5 feet. The depth of the crib below the surface at low water is 16 feet at the upper end and 10 feet at the lower. Upon two occasions fresh sand and gravel have been dumped in places upon the crib to replace material thought to have been washed away.

Hulton, Pa.—At Hulton, about 11 miles above Pittsburg, a crib similar to that at Montrose was built in 1894. Its timbers are 2 by 4 inch hemlock. It is 96 feet long, 16 feet wide, and 4 feet deep, and is covered to a depth of about 4½ feet with large stones, sand, and gravel. The average depth of water at low water is about 7 feet. Here similar exhaustive analyses were made both of the raw water of Allegheny River and of the effluent from the crib.

Analyses showing efficiency of crib at Hulton, Pa.

[Parts per million.]

Date.	Water analyzed.	Turbidity.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Bacteria per c. c.
1897.								
Aug. 9	River water, raw......	Slight............	0.215	0.021	None.	0.815	11.7	650
	Effluent from crib.....	Clear.............	.108	.009	None.	.592	35.3	135
Aug. 16	River water, raw......	Decided..........	.208	.021	None.	.900	11.0	525
	Effluent from crib.....	Slight............	.130	.014	None.	.605	24.0	1,071
Aug. 23	River water, raw......	Slight............	.185	.016	None.	.638	11.0	1,150
	Effluent from crib.....	Very slight.......	.130	.018	None.	.528	44.8	135
Sept. 14	River water, raw......	Slight............	.133	.024	None.	.450	19.7	250
	Effluent from crib.....	Very slight.......	.094	.016	None.	.450	29.7	68
Sept. 28	River water, raw......	Slight............	.174	.028	None.	.900	20.1	3,300
	Effluent from crib.....	Slight............	.102	.014	None.	.750	39.0	2,250
Oct. 5	River water, raw......	Very slight.......	.162	.012	None.	.775	31.2	12,250
	Effluent from crib.....	Clear.............	.096	.014	None.	.825	36.8	6,336
Oct. 12	River water, raw......	Slight............	.108	.010	None.	.600	28.4	5,700
	Effluent from crib.....	Very slight.......	.118	.005	None.	.825	39.7	3,846
Oct. 19	River water, raw......	Very slight.......	.105	.012	None.	.600	27.9	90,000
	Effluent from crib.....	Very slight.......	.090	.010	None.	.675	38.0	34,560
Oct. 26	River water, raw......	Very slight.......	.078	.014	None.	.375	37.5	87,000
	Effluent from crib.....	Very slight.......	.080	.016	None.	.525	51.4	39,825
Nov. 2	River water, raw......	Clear.............	.060	.012	None.	.450	35.1	32,000
	Effluent from crib.....	Very slight.......	.084	.014	None.	.450	53.4	27,000
Nov. 9	River water, raw......	Slight............	.122	.016	None.	.525	34.5	7,800
	Effluent from crib.....	Clear.............	.088	.018	None.	.525	63.1	2,100
Nov. 16	River water, raw......	Decided..........	.266	.054	None.	1.200	18.5	15,010
	Effluent from crib.....	Clear.............	.160	.058	None.	.825	62.2	100
Nov. 23	River water, raw......	Slight............	.140	.010	None.	.675	14.4	15,700
	Effluent from crib.....	Clear.............	.068	.014	None.	.450	60.7	167

In all but one of these thirteen sets of analyses a reduction of bacterial content is noted in the effluent, varying from the 6 per cent, removed September 28, to the 93 per cent, removed November 16. The highest efficiency, 93 per cent, is not sufficiently high to warrant the use of this water as a public supply; the lowest needs no comment. Lest it may be claimed that some further reduction in bacterial content takes place in the taps the following analyses are presented to show the condition of the effluent from the crib, side by side with that of samples from the taps in Verona, supplied from this source.

Analyses of water from Hulton crib and Verona tap.

[Parts per million.]

Date.	Water analyzed.	Turbidity.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Bacteria per c.c.
1897.								
Dec. 7	Effluent	Clear	0.048	0.016	None.	0.975	68.1	48
	Verona tap	Clear	.064	.014	None.	.825	65.1	175
Jan. 4	Effluent	Clear	.044	.018	None.	.750	22.7	93
	Verona tap	Very slight	.040	.022	None.	.675	26.0	444
Jan. 18	Effluent	Clear	.040	.028	None.	.825	50.4	952
	Verona tap	Clear	.038	.026	None.	.600	52.1	323
Feb. 1	Effluent	Clear	.028	.020	None.	.750	51.8	333
	Verona tap	Clear	.032	.014	None.	.825	49.2	1,980
Feb. 16	Effluent	Clear	.040	.016	None.	.825	44.5	861
	Verona tap	Clear	.042	.010	None.	.750	49.2	130

Analyses are available through August, 1898, but it is unnecessary to quote further. It is evident that the quality of the water in the taps is sometimes improved and sometimes not. In the five cases given three show an increase in bacteria; two a decrease. If pathogenic bacilli are in the water, there is absolutely nothing to prevent this water from carrying contagion from the infected river to every tap in Verona.

Sharpsburg, Pa.—At Sharpsburg (population about 7,000), on the west side of the Allegheny, a mile below Brilliant, the supply is derived from the river through a crib 100 feet long, 8 feet wide, and 5 feet deep. It has been in use since 1893. There is about 2½ feet of river material over it, but it is tight near the top, being open on the bottom and the lower part of the sides. Timbers and openings are 6 inches wide. Low water is about 3 feet above the top of the crib. There are no analyses at hand of the raw Allegheny water at Sharpsburg, but the average analyses of the Sharpsburg effluent, taken in connection with analyses made to determine the efficiency of the Etna crib, shown below, furnish sufficient data for judgment on the supply of the former.

Average analyses of effluent from Sharpsburg crib.

[Parts per million.]

Date	Turbidity.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Bacteria per c.c.	Bacteria range in number.
1898.								
May		0.056	0.019	None.	0.375	18.9	3,710	800- 7,450
June		.124	.016	None.	.300	19.4	15,800	11,100-20,500
July		.096	.016	None.	.750	20.5	13,400	13,000-13,800
August		.085	0.19	None.	.525	22.3	25,500	18,800-32,200

Evidently, whatever may be the nature of the purification this has undergone, its efficiency in removing bacteria is not high. Disease-infected water would therefore pass through this crib without sufficiently complete loss of organisms to make it reasonably safe for drinking.

Etna, Pa.—Comparative analyses of water at Etna show similar conditions. At this point there is also a crib in the river. It is a wooden box 40 feet long, 16 feet wide, and 4 feet deep, perforated with many openings and covered to the depth of about 4 feet with stone, river gravel, and sand. The following analyses show the efficiency of the crib:

Analyses showing efficiency of Etna crib.

[Parts per million.]

Date.	Water analyzed.	Turbidity.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Bacteria per c.c.
1897.								
Sept. 7	River water, raw	Slight	0.222	0.028	None.	0.750	21.0	6,125
	Effluent	Clear	.126	.018	None.	.975	30.2	1,288
Sept. 21	River water, raw	Slight	.186	.012	None.	.600	28.0	2,625
	Effluent	Very slight	.118	.014	None.	.900	42.3	133
Sept. 28	River water, raw	Very slight	.118	.024	None.	.812	22.1	5,250
	Effluent	Very slight	.098	.026	None.	.900	28.7	1,841
Oct. 5	River water, raw	Very slight	.188	.014	None.	.900	29.4	7,200
	Effluent	Clear	.090	.018	None.	1.500	41.0	1,652
Oct. 12	River water, raw	Very slight	.160	.032	None.	.600	32.0	28,750
	Effluent	Very slight	.148	.018	None.	.750	45.8	2,730
Oct. 19	River water, raw	Very slight	.122	.022	None.	.600	46.1	27,300
	Effluent	Very slight	.096	.010	None.	1.275	48.3	13,260
Oct. 26	River water, raw	Very slight	.144	.048	None.	.750	40.0	75,000
	Effluent	Clear	.056	.014	None.	.750	49.4	38,220
1898.								
June 7	River water, raw	[a] 0.3	.084	.042	None.	.300	23.8	65,800
	Effluent	Clear	.040	.006	None.	.300	51.5	5,200
June 21	River water, raw	[a] 9.0	.124	.028	None.	.150	14.0	16,400
	Effluent	Very slight	.030	.008	None.	.225	48.0	325
July 6	River water, raw	.09	.130	.030	None.	.750	18.7	1,630
	Effluent	Very slight	.058	.016	None.	.675	44.2	1,520
Aug. 2	River water, raw	1.8	.168	.036	None.	.450	30.0	239,000
	Effluent	Slight	.068	.018	None.	.525	48.6	10,850
Aug. 16	River water, raw	1.6	.120	.044	None.	.675	18.4	159,000
	Effluent	Clear	.070	.026	None.	.525	54.1	1,600

[a] Reciprocal scale.

These analyses indicate a higher degree of efficiency at times than has been previously noted, but they bring out strikingly the greatest drawback to crib filtration; that is, the lack of regularity in efficiency. During the summer of 1898, when the structure had been in place a year and should have shown as good results as it ever will, the efficiency is seen to vary from 98 per cent on June 21, already quoted, to less than 7 per cent on July 6. Before a city ventures to use the water of Allegheny River it should demand better assurance of purification than this.

Millvale, Pa.—At Millvale (population about 7,000), about 4 miles below Brilliant, on the western side of the river, there are two cribs, one of which is owned by the Bennett Water Company. This crib is 100 feet long, 16 feet wide, and 4 feet deep, built of 2 by 4 inch timber, and covered with stone, gravel, and sand. The flow of the current has necessitated frequent refilling to replace material washed away. At this crib the bacterial purification is so slight as to make detailed figures unnecessary. The averages are given below:

Determinations showing efficiency of Millvale crib.

1897.	Average number of bacteria in river water per c. c.	Average number of bacteria in effluent water per c. c.
August	4,600	7,533
September	3,762	4,144
October	69,126	41,669

That the crib had not improved much by the following August is shown by the fact that a sample of the effluent water taken August 2, 1898, showed 18,200 bacteria per cubic centimeter, and a sample taken August 16 showed 19,500 bacteria per cubic centimeter, both numbers too large to speak well for the process.

Wildwood, Pa.—A large quantity of water is pumped from the Wildwood crib, on Allegheny River, about 1½ miles above the Brilliant pumping station, to supply the town of Wilkinsburg, part of Pittsburg, and some neighboring places. The crib is in the middle of the river, 304 feet long, 32 feet wide, and 4 feet deep, built of 2 by 8 inch planks, with 2-inch open places on top and sides, and open bottom. Upon it and around it there were placed large stones to the depth of 1 foot, then 1 foot of coarse gravel, and then 3 feet of river sand. There is said to be 30 feet of gravel in the bed of the stream under the crib, which should improve the quality of the water. It was installed in June, 1897.

Analyses showing efficiency of Wildwood crib.

[Parts per million.]

Date.	Water analyzed.	Turbidity.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Bacteria per c.c.
1897.								
July 13	River water, raw	Slight	0.162	0.016	0.003	0.015	18.0	520
	Effluent	Clear	.046	.012	.001	.010	18.5	269
July 29	River water, raw	Muddy	.280	.031	None.	1.334	9.5	11,350
	Effluent	Clear	.032	.023	.005	.445	22.0	59
Aug. 4	River water, raw	Slight	.240	.030	.001	.950	11.5	1,225
	Effluent	Clear	.062	.018	.004	.592	14.5	88
Aug. 11	River water, raw	Muddy	.395	.035	None.	.814	37.5	3,600
	Effluent	Clear	.110	.024	.003	.370	21.2	50
Aug. 18	River water, raw	Slight	.268	.018	None.	.600	15.6	11,200
	Effluent	Clear	.052	.023	.003	.300	18.1	262
Aug. 24	River water, raw	Very slight	.204	.028	None.	.450	13.1	5,200
	Effluent	Clear	.060	.028	None.	.375	19.9	106
Sept. 7	River water, raw	Very slight	.122	.014	None.	.600	18.8	7,425
	Effluent	Clear	.048	.026	.001	.450	20.3	78
Sept. 14	River water, raw	Slight	.112	.012	None.	.575	21.4	300
	Effluent	Clear	.062	.018	None.	2.250	21.9	12
Sept. 21	River water, raw	Slight	.108	.028	None.	.300	26.2	825
	Effluent	Clear	.056	.012	None.	.225	21.5	160
Sept. 27	River water, raw	Slight	.118	.012	None.	.675	25.1	3,600
	Effluent	Clear	.040	.014	None.	.450	26.2	148

It is evident, taking the records pair by pair, that this crib has effected a very remarkable reduction in the organic content of the river water if the effluent really is filtered river water. On August 24 the efficiency was 98 per cent; on September 7, 99 per cent; on September 14, 96 per cent; on September 21, 80 per cent; on September 27, 96 per cent. During the month of October, 1897, it was steadily about 96 per cent. This is as high a percentage of efficiency as many mechanical filters make; but a noteworthy difference appears in the drop to 80 per cent on September 21. It is impossible to know just why this happened in the crib, whereas in the mechanical filter the difficulty could be found and remedied. In other words, the crib filter may, as in this case, give wonderfully high efficiency at times—even most of the time—but no one knows when it may fail for a brief period. Its operation is uncontrollable and uncertain, and in a stream so badly polluted with pathogenic organisms as the Allegheny the risk is too great to be taken. It is unfortunate that typhoid-fever statistics are unobtainable for this town except for 1899, when there were 5 deaths from this cause in a population of 11,886 (census of 1900), the death rate thus being 42 per 100,000.

If the efficiency previously noted were maintained, there should not be over 25 deaths per 100,000 from typhoid fever.

Summary.—The foregoing statement discusses filtering cribs operating under different conditions. Where the crib has been placed in a swift current of water its efficiency is practically too low for serious consideration; under peculiarly favorable conditions, such as those at the Wildwood crib, an amazingly high efficiency is realized for a time. The mass of data compiled as to the operation of slow sand filters shows that in time, whether it be one, two, or three years, the filtering sand and gravel must either become so much clogged as to diminish seriously the supply, or the bacteria caught by the particles of sand must pass farther and farther into the mass until the effluent is no longer pure enough to drink. It is possible to remove the polluted sand from a sand filter and allow the filtering action to begin over again on fresh material, but no such removal can occur in the case of a crib except through the scouring of the river bed in time of flood, etc., a very irregular and uncertain agency. The important point is that such a mode of filtration is beyond control by ordinary means and is only properly efficient when favorable conditions happen to be met more by good fortune than by anything else.

The inefficiency of the cribs at Allegheny and Pittsburg is well known. The city of Allegheny installed a crib in Allegheny River in 1897 at an immense cost. The inefficiency of this structure in filtering the polluted water may be seen from the following figures showing typhoid-fever mortality:

Deaths per 100,000 from typhoid fever at Allegheny, Pa., 1898–1902.

Year.	Deaths.	Year.	Deaths.
1898	38	1901	101
1899	107	1902	120
1900	93		

For Pittsburg, filter cribs in Monongahela River supplying the South Side and six boroughs of the city gave the following results:

Deaths per 100,000 from typhoid fever at Pittsburg, Pa., 1898–1903.

Year.	Deaths.	Year.	Deaths.
1898	71	1901	125
1899	110	1902	144
1900	144	1903	139

These figures are worse than Allegheny's. It is evident that the water supplied to these consumers was totally unpurified, so far as disease bacteria are concerned.

At Sharpsburg the figures are few, but sufficient to show a general infection every year. In 1895 there were 47 cases, with 4 deaths; in 1898, 33 cases, with 7 deaths; in 1899, 57 cases, with 6 deaths out of a total mortality of 72, or 8⅓ per cent. In 1902 there were 73 cases. As the population of the town is only about 7,000, the above figures have startling significance. Evidently in 1902 one person in every hundred had typhoid fever, many of them probably through drinking the polluted river water.

The foregoing discussion of crib filtration has reviewed figures showing bacterial purification and typhoid-fever mortality derived from absolutely reliable sources for several cities. In every case it has been shown that crib filtration, no matter how excellent the results may be at times, is absolutely unreliable as a means of ameliorating a public water supply.

FILTER WELLS.

General discussion.—The third method of natural filtration is by wells sunk in river sand and gravel, varying in diameter from a few inches to 20 or 30 feet, and so constructed as to

allow the polluted river water to seep through its own bed into the well. As has been already stated, this method of filtration produces a water of excellent appearance, but the data given relating to filter cribs and filter galleries show that there can be no real purification of the water by this means. It has seemed to be very possible that efficient filtration could be obtained by a modification of this plan where local conditions are favorable, as in some islands in Ohio River. If wells are drilled to a moderate depth on some of these islands of clean river sand, through which the water may percolate before entering the wells, very efficient purification ought to be secured until the outer layers of sand become clogged. The frequent scourings to which these islands are subject by the rise and fall of the river as well as by its strong current should be favorable to the periodical removal of the clogged layers. The idea is not new.

M. Leforte, Ingenieur des Ponts et Chaussees, engaged in improving the water supply of the city of Nantes, proposed a dozen years ago to secure artificially the most favorable conditions for natural filtration by creating at many places in the bed of the Loire, a little above the city, islets of fine sand, in the middle of which were established wells provided with suitable works for their control, from which water was to be taken. Notwithstanding a satisfactory trial of the process it was not applied.[a]

The same procedure was suggested by M. Janet, engineer of mines, who recommended that water be pumped from the Seine and the Oise to the summits of sandy hills at Montmorency, Fontainebleau, etc., and allowed to percolate to the bottom of the sand to be collected, thus making use of a natural filter over 50 meters thick.

Gallipolis, Ohio.—It has remained for an American municipality to apply this plan and to demonstrate its ultimate inefficiency. The city of Gallipolis, Ohio (population about 6,000), gets its water supply from filter wells drilled on an island in the Ohio River. The records of typhoid fever mortality show a wonderful temporary efficiency, not a single death from this cause being reported during two years, at the end of which former conditions recurred.

Typhoid mortality at Gallipolis, Ohio.

Year.	Total deaths.	Typhoid deaths.	Year.	Total deaths.	Typhoid deaths.
1897	116	2	1901	57	0
1898	146	3	1902	83	8
1899	101	7	1903	65	4
1900	64	0			

Evidently if the decrease in deaths is to be ascribed to the filtration of Ohio River water through this river sand the return to the epidemic conditions shown in 1902 and 1903 must have had a similar origin. It is probable that the pathogenic organisms carried in the river water have grown completely through the sand, so that even the scouring of the top does not carry away all the polluted sand. The experiment shows the uncontrollable character of such a purification scheme.

Similar supplies exist at Moundsville, W. Va., and Point Pleasant, W. Va., both described later in this paper (pp. 87, 92–93).

CONCLUSION.

Every form of natural filtration so far attempted has been unsuccessful except the rather rare type last described, and that was successful only for a time. At many other places which could be cited the death rate shows that these devices have no efficiency in removing bacteria from polluted water, so that towns which attempt to purify water by natural filtration are likely to spend more money annually in avoiding epidemics of water-borne diseases than many times the interest on the cost of an efficient sand-filtration plant.

[a] Trans. Am. Soc. Civil Eng., vol. 54, Pt. D, p. 184.

SELF-PURIFICATION.

OXIDATION, DILUTION, AND SEDIMENTATION.

The conditions on the Monongahela (see pp. 54–55) show the existence of sources of pollution sufficient to make the river water unsafe as a source of public supply without purification, unless complete self-purification takes place in the river. If Professor Sedgwick is correct in his conclusion[a] that the population of the Allegheny basin scattered along the main stream and its tributaries is practically equivalent under present conditions to an equal population massed at the lowest point considered, then the same conclusion applies to the more concentrated population of the Monongahela basin with drainage slopes as far down as Greensboro steeper than those of the Allegheny. It would seem, then, that the contamination in Monongahela River from above Point Marion is probably equivalent to that of a city of 25,000 or 30,000 population located at Point Marion, and the question arises whether complete self-purification takes place below that point.

From a drainage area of 11,400 square miles Allegheny River discharges, as is shown by official measurements made by the U. S. Geological Survey, from 1,312 cubic feet per second (September, 1903) to 40,000 cubic feet per second or more at flood stages. Monongahela River has a drainage area of 7,625 miles, 67 per cent of that of Allegheny. Its discharge can not be given with accuracy since few figures are available. The discharge of the Youghiogheny at Ohiopyle, Pa., measured by Kenneth Allen in 1892, was 106 cubic feet per second at a very dry time; Indian Creek, entering some miles below, usually carries 50 to 100 feet per second, but has been known to go as low as 12 cubic feet per second in periods of extreme drought. The table herewith shows the flow of Indian Creek as computed by the Geological Survey[b] from data furnished by Charles H. Knight, Rome, N. Y., in 1893.

Estimated mean flow of Indian Creek from August, 1892, to July, 1893.

	Sec.-ft.		Sec.-ft.
August	31.4	February	659.0
September	15.2	March	290.5
October	12.6	April	278.0
November	48.8	May	523.3
December	102.8	June	41.3
January	193.5	July	13.1

The table giving the discharge of Cheat River shows that that stream at times carries less than 200 cubic feet per second. In October, when Indian Creek is at its lowest, Cheat River carries about 700 cubic feet per second. It may be roughly estimated that Cheat River, Indian Creek, and Youghiogheny River together contribute about 825 cubic feet per second to the Monongahela in the fall. The discharge of Tygart and West Fork rivers aggregates about 75 cubic feet per second. No figures are available for these streams, and this is merely a rough estimate based on experience in measuring similar streams. Altogether the Monongahela may be said to carry about 900 cubic feet per second in the fall, or about two-thirds the volume of Allegheny River at that time. The flood flow of the Monongahela is considerably over 40,000 cubic feet per second, or about the same as that of the Allegheny. The facts about the Monongahela are therefore as follows:

1. The drainage area of Monongahela River is 67 per cent of that of the Allegheny, and its discharge is about 70 per cent of that of the latter.
2. The flood discharge is nearly the same for the two streams.
3. As far down as Greensboro the Monongahela drainage area is rugged, the soil lacks fertility and therefore absorbs very little storm water, and the run-off is rapid.
4. The region is practically deforested.

These facts indicate that the Monongahela, as far down as Greensboro, is by far the quicker

[a] Rept. Pittsburg Filt. Com., p. 20.
[b] Water Sup. and Irr. Paper No. 65, U. S. Geological Survey.

spilling of the two streams, and as it has at its headwaters about the same population per square mile of drainage area it will deliver as much pollution to any point above Greensboro in the same time or less.

From Greensboro to Pittsburg, a distance of approximately 80 miles, the Monongahela has a fall of about 72 feet, or about 0.9 foot to the mile. This is so little compared to that above Greensboro that evidently it is on the conditions prevailing in this stretch of the stream that self-purification of the stream will depend. The element of time is of the greatest importance in this process. If the rate of flow of the water is so low as to detain pollution a long time, then the river will be practically a long, narrow reservoir, affording conditions more or less favorable for self-purification. But the rate of flow depends on slope, cross section, and quantity of water. The slope of the Allegheny from the mouth of Clarion River to Pittsburg, a distance of approximately 85 miles, is about 1.95 feet to the mile. The lower slope of Monongahela River would tend to lessen the velocity of the water and lengthen the period of detention. The latter may be said to be inversely proportional to the rapidity of flow, or

$$\text{Detention} = \frac{1}{V}, \quad \text{where } V = c\sqrt{rs}$$

the Chezy formula usually employed in computation of flow in open channels. If fairly accurate data were obtainable for cross sections of the two streams at numerous points, the formula could be used to express numerically the degree of detention, and hence the degree of self-purification going on in a given stream. In this case the lack of such data is complicated by the fact that the Monongahela is so completely canalized below Greensboro as to make the slope above calculated valueless for this discussion, as the fall of each slack-water basin is practically zero. At low water, therefore, the velocity of the water is so very slight as to give an enormously high value for detention in the proposed formula, pointing to an infinitely high degree of purification. For streams not canalized the degree of self-purification would seem to be directly determinable.

If pollution be supposed to enter the Monongahela at Greensboro only and all sources of contamination below that point to be eliminated, the degree of self-purification going on in the 80 miles under discussion is so high that it is conceivable that the water might be completely purified. But it is not at all certain that this is the case. It is now agreed by sanitarians that the process of self-purification can hardly be complete and perfect, and that therefore it can not be depended upon as sufficient in itself to assure a pure supply.

The main factors in self-purification are evidently oxidation, dilution, and sedimentation, and for the last the term "detention" is proposed as more properly expressing the time element necessary. As far as oxygen is concerned it has long been known that the typhoid bacillus, the very organism it is desired to eliminate from water, "grows most abundantly in the presence of free oxygen," though "it may also develop in its absence."[a] It is well known to bacteriologists that "the great majority of pathogenic bacteria are facultative anaërobes"[b]—that is, they may develop with or without oxygen. As to dilution of sewage, Professor Sedgwick believes that 1 gallon of sewage dumped into Illinois River might cause trouble in the water supplies below. Without going to this extreme, it is perfectly evident that no lines can be drawn between "sufficient" and "insufficient" dilution. It takes little sewage, compared to the volume of the stream, to cause an offensive appearance. Very little is necessary to poison the water for drinking. The question resolves itself into one of the vitality of pathogenic organisms in water, a question discussed later in this paper.

The exact amount of self-purification due to sedimentation can not be stated positively. Turbidity has a great influence on purification by sedimentation, for turbid water contains many heavy particles which settle to the bottom, entangling and carrying with them great numbers of bacteria as they go down. Long detention, therefore, will cause turbid water to become not only clearer, but remarkably better in quality, by causing the greater part of the pollution to settle to the bottom. In running water sedimentation can not occur to any great degree unless the current is retarded by obstacles, natural or otherwise, which convert

[a] Sternberg, Bact., 1896, p. 358. [b] Muir and Ritchie, Bact., 1899, p. 23.

the river into a chain of pools, and the greater the number of pools or reaches on the river and the closer together they are the more will self-purification be assisted.

The mill pond at Lowell, Mass., is 16 miles long. The well-known epidemic of typhoid fever at this place was traced to dejecta, principally from one patient, which entered a large brook from an overhanging outhouse, was delivered into the Merrimac, and reached the intake of the waterworks. At Lawrence, Mass., an equally well-known epidemic was caused by contaminated water which had been kept in the storage reservoir two weeks, with excellent opportunity for sedimentation. At Covington, Ky., the badly polluted water of Ohio River is kept at times as long as thirty-two days, yet Covington suffers severely from typhoid fever. At New Albany, Ind., the water supplied to the city is stored for a month before it is used, yet there is much typhoid fever.[a] These instances show that sedimentation alone, under the best conditions, does not make contaminated water safe. Settling basins alone are not an efficient and adequate means of purifying the sewage discharged into a stream.

Decisive evidence on this head is supplied by the schematic representation made for the Report of Streams Examination for the Sanitary District of Chicago, showing the belief of some water bacteriologists that the polluted water from Chicago is completely purified by the time it reaches Averyville. The drawing shows pollution in heavy black shading; lightening as the purification goes on, proceeding down the river. The pollution is heaviest at Chicago and gradually thins out until it reaches Averyville, when it disappears, to be renewed presently by the sewage of Peoria. This diagram is the result, presented in graphic form, of numerous bacteriological analyses of the river water by the commission. The distance from Chicago to Henry, where the sewage has very largely disappeared, is about 114 miles; from Chicago to Averyville, where apparently it has wholly disappeared, about 142 miles; from Peoria, with its heavy pollution, to Kampsville, where it is claimed that that pollution has disappeared, about 150 miles. Therefore, without going into the merits of the Chicago-St. Louis controversy at all, it may be said that both parties agree that within about 100 miles of the source of pollution self-purification is so incomplete that contamination is recognizable, and that the infection of a stream of the character of the Illinois by the sewage of Chicago may be dangerous to the health of communities using the infected water raw within that distance.

Conditions on one stream can not be exactly like those on another. Illinois River, carrying the sewage of an immense population, is not in any respect exactly like the Monongahela. Yet a comparison of the two streams brings out similarities. The discharge of the Monongahela has been computed at roughly 900 cubic feet per second or 54,000 cubic feet per minute. That of Illinois River at Peoria at the same season of the same year, in September, 1903, was about 15,000 cubic feet per second or 900,000 cubic feet per minute. The population of the Monongahela drainage area above and including McKeesport may be assumed at about 134,000. That of the Illinois River drainage area above Peoria would probably be at least 2,250,000. These figures show the proportion—

$$54{,}000 : 134{,}000 :: 900{,}000 : x, \text{ whence}$$
$$x = 2{,}233{,}000,$$

almost exactly the population of the Illinois drainage area. The volumes of the two streams therefore, even allowing for errors in estimating, are practically directly proportional to the population served. There are numerous lakes and sluggish reaches on Illinois River where the fall is practically zero, so that there is probably as much opportunity for self-purification by detention in that stream as in any. It is unnecessary to enter into further details. It is evident that the uncertainty of self-purification on over 100 miles of Illinois River applies with great force to the conditions on the Monongahela, notwithstanding the difference in population.

The history of epidemics has repeatedly shown that it is not necessarily an extensive outbreak of typhoid that starts another below it, but that one or two cases may infect a large population. A few instances will be given. The typhoid-fever epidemic at Lowell, pre-

[a] Sedgwick, W. T., Test., Chicago Drain. Com. vol. 3

viously referred to, was traced to contamination from but one or two cases. The New Haven epidemic was caused by dejecta from typhoid-fever patients in one family passing into the water-supply reservoir. In the Windsor epidemic infection was washed by ordinary rains into a small thread of a stream and thence into a larger brook, which delivered it into the reservoir. The epidemic at Ithaca, which attracted so much attention, was due to the washing into the city supply of fecal matter deposited on the watershed. Scores of similar cases could be cited. The smaller population of the Monongahela is therefore no bar to the spread of typhoid fever by the use of the raw water. The industries along the river employ many foreign laborers—ignorant, uneducated, and of uncleanly habits—whose dejecta all go into the stream. This fact is well known, and the sole protection of the communities using the water has been the germicidal effect of detention in the chain of slack-water basins that constitute the lower Monongahela. It is clear that such purification is not certain nor perfect, and that there is grave risk in using this water raw.

The foregoing discussion started from the tentative assumption that no pollution enters the Monongahela below Greensboro, and it has been shown that contamination introduced at that point may live to reach the mouth of the river. As a matter of fact, however, fresh and dangerous sewage pollution enters the stream at hundreds of places below Greensboro, sometimes in enormous quantity. The real efficiency of the detention going on in the 80 miles of slack water is therefore measured by the efficiency of the last basin receiving pollution or the last basin on the river. The above discussion makes it evident that such a basin, even several miles long, can not be relied upon to completely purify polluted water.

Nor should it be forgotten that to settle the bacilli to the bottom of the basin is by no means to get rid of them. If by any means the mass of corruption at the bottom is disturbed, there is nothing to prevent it from being returned to the stream to be carried down to breed disease in towns below. This has been shown by the typhoid epidemic at Detroit, which resulted from the disturbance of sewage deposits in the bed of Black River at Port Huron. This caused sediment to be carried down St. Clair River through St. Clair Lake into the intake of the waterworks.[a] Professor Sedgwick well sums up the situation as follows:

> Dams undoubtedly so far as they produce slack water or quiescence favor purification and the disappearance of disease germs for the time being; but if the sediment or sludge is allowed to remain in the bottom of the stream and not removed artificially or taken out and put off out of a position of danger the chances are good, as experience shows, that in freshets it may be returned to the stream again, become a part of it, travel with it, and produce trouble below. That was the case at Newburyport. * * * The Merrimac is often a series of mill ponds or a series of quiet lakes in which sedimentation goes on nicely, and the water shows great purification at such times, but just as soon as a thunder shower comes [scouring takes place with the rise of the stream].

In other words, detention while undoubtedly of very great value in many cases does not and can not take the place of steady and regular purification of the stream by such a process as sand filtration, so that however great may be the improvement by detention the detained water must always be regarded with suspicion and once polluted can not be considered perfectly safe for drinking without being filtered.

It can not be held that the greater dilution of sewage in the Monongahela in times of flood is of assistance in purification. In the first place it is sufficiently evident that mere dilution can not be a complete safeguard. In the second place all the beneficial effects of detention gained by the slow current in the river may be nullified by a slight increase in velocity.

> The addition of such a volume of liquid as passes through the Drainage Canal must often materially quicken the flow of the Illinois River. It must, therefore, hinder effective sedimentation, and by thus shortening the time required for infectious germs to pass through the river and by interfering with their detention aggravate the danger of their arrival at the mouth of the river. * * * The time allowed in these matters is very important, so that any quickening of flow is a grave consideration.[a]

How much more grave becomes the interference with purification when a stream like the Monongahela rises within a few days, as it did twice in March, 1905, from about 9,000 cubic

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[a] Sedgwick, W. T., Test, Chicago Com., vol. 3.

feet per second to over 40,000 cubic feet per second, or from 540,000 cubic feet per minute, about six-tenths of the discharge of Illinois River at Peoria, to over 2,400,000 cubic feet per minute, nearly three times the discharge of the Illinois. This enormous increase in volume is bound to wash out the great mass of pollution that has accumulated at the bottom, which will be carried downstream into the water supply of every city that uses the river water raw. Any increase in the speed of the current increases the liability to the spread of typhoid fever under the conditions given.

ACID MINE-DRAINAGE.

There remains for discussion the theory held by some persons that the mine wastes that enter Monongahela River along much of its course containing much acid are sufficiently germicidal in their effects to insure reasonable safety in the use of this water in its raw state. This conclusion is not warranted by the facts.

The mine wastes present in this stream enter principally in the form of ferrous sulphate, though free sulphuric acid is sometimes distinguishable. The lime content of the stream is considerable, and this, together with the free acid and sulphate of iron, evidently brings about a coagulation and sedimentation which also drags down the organic impurities. This action is similar to that of the coagulating processes used extensively in mechanical filter plants as a preliminary to filtration. As is shown by the tables given below, this process is useful in clearing a muddy or highly colored water, such as that of Mississippi River; but it is the practically unanimous opinion of engineers that such purification, although exceedingly valuable in many cases and indispensable in some, can be regarded only as a preparation of the water for filtration and is by no means as adequate in itself to assure its safety for drinking.

The treatment of the St. Louis water supply by this process has attracted attention, and is regarded by local authorities as sufficient to safeguard the public health. Doctor Snodgrass, city bacteriologist of St. Louis, admitted before the American Public Health Association, in 1905, that the chemicals are added for coagulating purposes only, and that the completion of the process of purification must be accomplished by filtration. This treatment of contaminated water for use as a source of city supply, without filtration, can be regarded only as a device for diminishing danger, not as a means of abolishing it. "It does not provide pure water for the city. It is simply a makeshift."[a]

Its percentage of efficiency in removing bacteria seems at first glance very high, as is shown in the table herewith:

Efficiency of coagulation at St. Louis waterworks in removing bacteria.

Week commencing—	Number of bacteria in river water.	Number of bacteria in outlet water.	Number of bacteria in tap water.	Percentage of bacteria removed between river intake and outlet.	Percentage of bacteria removed between river intake and tap.
1904.					
March 28	19,000	8,700	937	55	91
April 1	187,500	....	9,200	....	95
April 22	34,000	8,225	1,550	76	95.5
April 29	136,500	2,850	3,950	98	97
May 6	22,500	1,800	550	92	98
May 13	103,500	37,500	16,250	64	85
May 27	45,000	600	750	99	98
June 3	30,000	3,500	600	89	98
June 10	24,000	1,100	2,000	95.5	92
June 17	16,000	550	500	97	97
June 24	38,000	1,600	650	96	98
July 15	26,000	4,300	323	84	98.8

[a] Weston, Am. Pub. Health, XXX.

Efficiency of coagulation at St. Louis waterworks in removing bacteria—Continued.

Week commencing—	Number of bacteria in river water.	Number of bacteria in outlet water.	Number of bacteria in tap water.	Percentage of bacteria removed between river intake and outlet.	Percentage of bacteria removed between river intake and tap.
1904.					
August 12	27,000	2,500	1,100	91	96
August 15	14,000	3,200	1,550	77	89
August 19	10,575	450	590	96	94.5
August 26	9,150	300	30	97	99.6
September 2	2,100	200	20	91	99
September 9	17,750		75		99.6
September 16	11,275	4,550	600	60	95
September 23	14,375	300	375	98	97.5
September 30	25,475	300	55	99	99.8
November 18	8,125	300	950	97	89
November 25	40,000	6,100	1,000	85	76
Average				87.4	94.7

The efficiency of a purification system may very justly be held to be the lowest percentage of removal of bacteria that it accomplishes. On this basis the efficiency of this system would be low indeed, sometimes going down to 76 per cent, and apparently not under such influences as can be controlled or regulated. The average removal of bacteria at the outlet of the sedimentation reservoirs is 79 per cent, and in the city taps is 94 per cent. If the latter figure be accepted as the regular daily performance of the process, it can not be considered thorough enough to warrant the use of the treated water without filtration. Effective sand filtration will remove over 99 per cent of the bacterial contents of polluted waters. The difference—about 5 per cent—may mean a great deal if the original bacterial content of the water be high and the sources of pollution not far removed. The experience of Lawrence, Mass., is significant. At this city 93 or 94 per cent of the total number of the bacilli in the polluted Merrimac River water were removed by storage in the city reservoir. Nevertheless typhoid-fever epidemics recurred year after year, showing that enough pollution was left to spread disease. The death rate from typhoid fever in this city is now one of the lowest in Massachusetts, with the filters removing 99 per cent of the pollution. The difference of 5 per cent there was evidently the difference between a poisoned supply and a healthful one.[a]

The treatment at St. Louis is made with great care, under the best conditions, calculated quantities of chemicals being added to the water, which is sedimented in basins not exposed to uncontrolled or irregular variations in depth, wind action, velocity of flow, quantity of water, etc. Nevertheless, as shown above, the degree of purification is not sufficient to make a water so treated safe without subsequent filtration.

How much efficiency, in the face of the above evidence, can be claimed for the coagulating process going on in the Monongahela River, with every element of the problem dependent on chance? Even if the process were carried on under the most favorable conditions purification could not be expected in the Monongahela water, because the chemicals are not present in sufficient amount. At St. Louis, iron is added to the water at the rate of from one-half to three grains per gallon. The minimum rate, one-half grain, is equivalent to 8½ parts per million of iron, which is necessary to purify the water in the partial degree already described; the water of the Monongahela River generally contains less than one part per million of iron, and seldom more than four.[b]

[a] Clark, H. W., Am. Pub. Health, XXX.
[b] Rept. Pittsburg Filtration Com., Analyses, p. 271.

The possibility that there is enough free acid in the water to destroy pathogenic bacteria is worthy of consideration.

The experiments made by various workers to determine the germicidal efficacy of sulphuric acid have been sufficiently numerous and extended to permit definite conclusions on the question to be formed. Many years ago Koch[a] first announced that the cholera bacillus was fatally affected by acid solutions. Subsequently, Kitasato[b] showed that cholera bacilli are destroyed in a few hours by hydrochloric and sulphuric acids. Davaine[c] had shown that the bacilli of anthrax are destroyed by sulphuric acid in the proportion of 1 to 5,000 and that the bacilli of septicemia are destroyed by the acid in the strength of 1 to 1,500. In Sternberg's experiments of 1885 it was shown that the multiplication of putrefactive bacteria was prevented by the presence in a culture solution of sulphuric acid in the strength of 1 to 800, and the micrococci of pus were destroyed in two hours by the presence of the acid in a solution of 1 to 200. The work of Boer, quoted by Sternberg,[d] showed the germicidal effect of sulphuric acid on the following organisms:

The anthrax bacillus was destroyed in two hours in a solution of 1 to 1,300.

The diphtheria bacillus was destroyed in two hours by a solution of 1 to 500.

The typhoid bacillus was destroyed by a solution of 1 to 1,550.

The spirillum of Asiatic cholera was destroyed in two hours by a solution of 1 to 1,300.

Stutzer showed[e] a solution of 0.05 per cent of sulphuric acid was fatal to cholera bacilli in fifteen minutes. A weaker solution (0.02 per cent) took twenty-four hours to kill the organisms, while a 0.03 per cent solution failed to kill the bacteria in five hours. As a result of his experiments, he estimates that 100 kilos of sulphuric acid at 60° Beaumé would disinfect 40,000 liters of water, a strength of 1:400, or 1 pound of acid to 40 gallons of water.[f] In the same year Doctor Ivanhoff showed[g] that a 0.04 per cent solution of sulphuric acid destroys cholera bacilli in Berlin sewage and an 0.08 per cent solution destroys the organisms in Potsdam sewage. Rohe showed that sulphuric acid in a proportion of 1 to 800 is antiseptic in some cases. He does not believe, however, that it can be depended upon as a general antiseptic.[h] The experiments of Kitasato quoted by Rideal[e] show that in a 0.049 per cent solution of sulphuric acid there is growth of bacteria; in a 0.065 per cent solution growth is restrained; in a 0.08 per cent solution growth cases. The experiments of Rideal and Parkes in 1900, to devise a portable disinfectant for use by soldiers in purifying drinking water, showed that chemically pure sulphuric acid diluted in the proportion of 20 minims to the pint of infected water reduced the number of bacilli in fifteen minutes and killed them in forty-five minutes. The amount of water used was 750 cubic centimeters, which was infected with 1 drop of a twenty-four-hour 37-degree broth culture of bacillus typhosus. Further, 100 cubic centimeters of boiled water infected with 1 cubic centimeter of the same culture gave the following results, the plus (+) sign indicating the presence of the organisms, the minus (=) sign their absence:

Effects of sulphuric acid on bacilli.

Minims per pint of infected water.	Results.					
	7½ minutes.	15 minutes.	30 minutes.	45 minutes.	60 minutes.	2 hours.
20	+	+	+	+	–	–
15	....	....	+	+	+	–
10	....	....	....	+	+	+

[a] Virus de Septicémie; Gas. Med., Jan. 10, 1874.
[b] Quoted in Sternberg, Bact., 1896.
[c] Bact., 1896.
[d] Zeit. für Hyg., 1893, p. 116, quoted by Rideal.
[e] Disinfection and Preservation of Food, 1903, p. 375.
[f] The English imperial gallon is equivalent to 10 pounds.
[g] Zeit. für Hyg., 1893, p. 86.
[h] Hyg., 1890, p. 357.

The largest amount used, 20 minims to the pint, or 1:384, about 2,600 parts per million, would take an hour to kill typhoid bacilli under conditions closely resembling the actual conditions.

The most important of all experiments of this kind, perhaps, and those which apply most closely to the problem under discussion, were those made by Rideal to determine the vitality of the typhoid organism. Typhoid-fever bacilli were introduced into impure water, which was kept at room temperature, with the following results:

Effect of sulphuric acid on typhoid fever bacilli.

Strength of solution.	Time of exposure.	Results.
Per cent.	*Hours.*	
0.025	20	Killed.
.030	½	Alive.
.030	20	Alive.
.030	½	Killed.
.035	½	Killed.

All these experiments show conclusively that sulphuric acid can and does kill organisms in water, but the question remains, How far are these facts applicable to the problem of the purification of the water in Youghiogheny River?

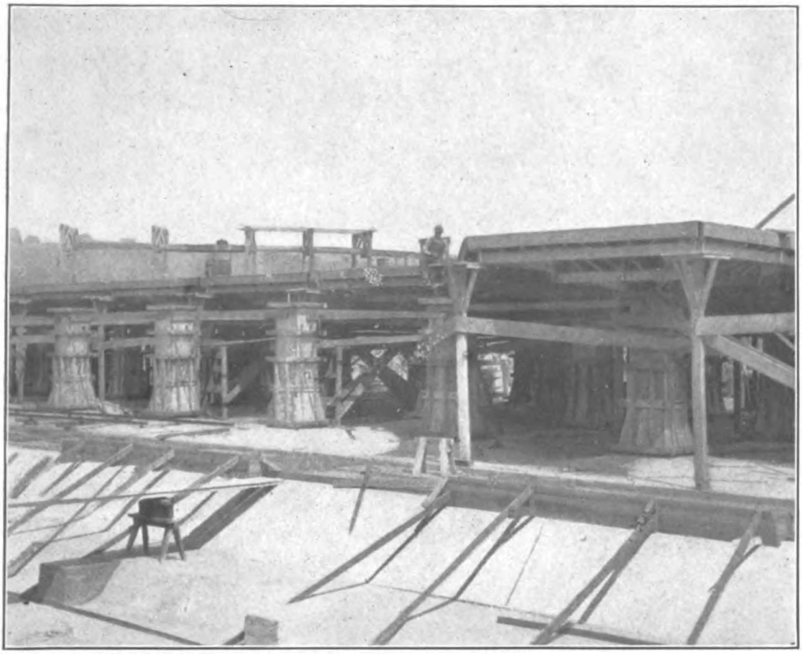
Certain conditions in the problem under discussion show that the action of the acid is valueless as a means of purification.

1. There is never sufficient acid to do the work.

2. It is impossible to apply the acid in constant quantity, owing to the wide variation in the flow both of the stream and the acid, the former being subject to wide and rapid variation, while the flow of acid may be as high as 30 or 40 parts per million at some periods and may cease altogether at others, as shown by the analyses.

Rideal's experiments show that a 0.025 per cent sulphuric-acid solution, equivalent to 250 parts per million, requires 20 hours exposure in impure water at room temperature to kill typhoid bacilli, while a solution of 350 parts per million (0.035 per cent) will kill the organisms in half an hour. There is never so much sulphuric acid in the water of Monongahela or Youghiogheny rivers. As shown above, at one time, in August, 1905, the amount was so small as to be undistinguishable by field-assay methods which readily distinguish a slight trace, amounting possibly to one-fiftieth part per million. The analyses made for the city of McKeesport, referred to above, show 44 parts per million of the acid uniformly distributed through the body of the stream and never as many as 100 parts per million, except possibly at isolated points immediately below the outflow of mines. It is clear, therefore, that although sulphuric acid is a germicidal agent under favorable conditions, such conditions do not and can not exist in the rivers under discussion, and the acid can not be counted on to purify them of sewage bacteria. Even if there were more acid present, it is to be remembered that its strength is not entirely available for the elimination of pathogenic bacteria. "A chemical disinfectant will frequently combine almost instantly with organic or other matters present in sewage, thereby becoming partially or entirely inert before it has time to attack the bacteria."[a] If 200 or 300 parts per million of sulphuric acid were being poured into the river, there is so much lime and other alkaline material present that the greater part of the acid would immediately combine with these to form merely a neutral sulphate instead of persisting as a free germicide. This difficulty has long been encountered in the various attempts made to chemically sterilize sewage. Sulphates are not germicidal at all, and only moderately antiseptic; the difference, be it

[a] Rideal, S. S., Disinfection and Preservation of Food. New York, J. Wiley & Sons, 1903.



A

B

PITTSBURG FILTER PLANT.

A, Collecting galleries; *B*, main conduit.

said, for nontechnical readers, being that an antiseptic will restrain or check the growth of bacteria while germicides kill them. Though the recent notable study of copper sulphate as a disinfectant of water supplies by Moore and Kellerman and others[a] has shown that under some conditions it is destructive to certain forms of bacteria, the sulphates of lime and magnesia actually encourage the growth of some organisms, while the sulphates of iron depend for their antiseptic power not on the acid but on the metallic base present; and this is probably the effective agent in the copper sulphate. Miquel classed iron sulphates as moderately antiseptic; finding that 11 grams per liter, which is equivalent to 1.1 per cent, were required to prevent the putrefaction of beef juice—that is, to prevent the growth of putrefactive bacteria in a food medium. Certainly no such enormous proportion of iron sulphate (11,000 parts per million) is ever present in the river water.

The people who have been using this water on the assumption that it is free from dangerous pollution have been relying principally on the statement, made by certain persons and repeated by others without investigation, that sulphuric acid is a germicide and that there is enough of it in the stream to purify the Youghiogheny River water. In depending on the antiseptic action of sulphuric acid to kill pathogenic organisms in Youghiogheny River water, the people of McKeesport and other cities drinking such water are making a mistake which has cost many lives and many thousands of dollars annually.

PUBLIC WATER SUPPLY AT PITTSBURG, PA.

The attention of sanitarians has for years been focussed on Pittsburg, on account of the notoriously high death rate from typhoid fever in that city. The Pittsburg Filtration Commission of 1897 so thoroughly investigated the questions of the pollution of the present sources of supply and of the possible sources of pure water as to make extended remark on this subject quite unnecessary here. The preceding discussion of the quality of water and drainage on both watersheds supplying this city should be sufficient to show the character of the supply. It is drawn directly from the running streams, without attempt at purification, to reservoirs too small to permit sedimentation for periods longer than a few days, after which the water enters the mains. The Filtration Commission showed the necessity for immediate and thorough filtration of the water if the typhoid death rate is to be in any great degree diminished, taking up the Allegheny River watershed in detail.

The filtration plant now in course of erection under the superintendence of Mr. Morris Knowles contemplates the use of Allegheny River water after sand filtration of the most thorough description. The plant is located on the river at Aspinwall, about 5 miles north of Pittsburg, nearly opposite the Brilliant pumping station. The new pumps on the Aspinwall side will pump the river water into sedimentation basins, two in number, at the upper edge of the site, whence the somewhat clarified water will enter the central chamber and proceed to the filter beds, of which there will be 50 or more, as the needs of the town may require. Although some difficulty is being encountered with soft ground, necessitating the driving of concrete piles, and with the building out of the river bank, for which gravel is being dredged from the river, the bank being faced with firmly anchored concrete blocks, the work is proceeding rapidly, a few of the filter units being already finished. Pl. IV shows sections of the work under way. The vaulting and floors of the filter beds are of standard construction in essential features. A noteworthy detail is the filter gallery between beds, a concrete passage where the purified water as it leaves the filters will be caught and carried toward the river, where it will be taken up by the Brilliant pumps and drawn across the stream. The line in the bed of the stream is in process of construction, a cofferdam being built out from the ends of the pure-water pipes to the Brilliant side. On the Aspinwall side the two pure-water pipes have been so constricted as to form two huge Venturi meters for the measurement of the pure water supplied from the filters. The view of the main conduit running along the upper side of the beds shows a small portion completed and the grade blocks set ready for further construction. When completed the plant

[a] Jour. New England W. W. Assoc., 1905.

should be one of the finest in America, and will probably add a very important chapter to the history of decrease in typhoid fever with filtration of a polluted supply.

The quality of these river waters at Pittsburg is shown by the field assays of the two streams and of Ohio River below their confluence:

Field assays of water at Pittsburg.

[Parts per million.]

Determination.	Allegheny River at Pittsburg.	Monongahela River at Pittsburg.	Monongahela River at Carnegie (tap).	Ohio River at Pittsburg.
Turbidity (SiO_2)	0	....	Cloudy.	55
Color	106	70	35	122
Iron (Fe)	1	1.5	1.5	2
Calcium (Ca)	42	65	90	56
Total hardness (as $CaCO_3$)	26.5	61	85	61
Alkalinity	51.4	23	22.6	47.4
Sulphates (SO_3)	[a] 15	84	83	[a] 20
Chlorides (Cl)	10.7	16	10.3	26

[a] Estimated.

It is notable that though the two Monongahela samples are practically identical in iron, sulphur trioxide, and alkalinity contents, the three factors which best show the effect of mine drainage, the Carnegie water has a little more calcium, with a consequent increase in total hardness. This is probably due in part to the absorption of calcium from the reservoir at Carnegie, in part to the possible admixture of limestone spring water. The South Pittsburg Water Company, which pumps from Monongahela River, supplies the South Side, several wards of the city proper, and many thousands of people along the line out to Carnegie.

The turbidities given in the Allegheny and Monongahela assays are only approximate, the water being slightly cloudy in both cases. The turbidity given for the Ohio River water, however, is the result of careful measurement with the turbidity rod, and shows a significant increase in suspended matter.

OHIO RIVER BASIN BETWEEN PITTSBURG, PA., AND BIG SANDY RIVER.[a]

GENERAL STATEMENT.

With the sewage of half a million people entering the stream, besides an enormous amount of drainage from mills and factories, as well as a great quantity of material dumped into the stream from the numerous craft plying in the three rivers at this point, Ohio River below Pittsburg is to all intents and purposes an open sewer. The increase in color downstream tends to strengthen this view, as does the increase in iron content, though the effect of the dilution by Allegheny River is to lessen the amount of sulphur trioxide in the water. The calcium content is practically an average of that of the two streams. The chlorides are so much higher than those of either the Allegheny or the Monongahela that they are undoubtedly traceable in part to the enormous sewage contamination. Bearing in mind the conclusions already reached with respect to the quick-spilling character of these watersheds and as to the massing of population near the mouth of the stream, we may say that the Allegheny above Pittsburg is as highly infected as if 100,000 people were massed at that point, and that the Monongahela is as badly contaminated as if there were a similar number located on its course immediately above Pittsburg. The population of Pittsburg being at

[a] Pollution on tributaries of Ohio River in Ohio is discussed in Water-Sup. and Irr. Paper No. 79, U. S. Geol Survey, pp. 129-187.

least 300,000 it may safely be said that Ohio River below Pittsburg is contaminated by the sewage of at least 500,000 people, which enters the stream untreated, carrying with it contamination from thousands of typhoid-fever cases, of a virulence shown by the tables of death rate from this disease given above. Any water drawn from the Ohio at this point must be purified to a high degree in order to be safe for drinking. The only sense of safety in communities using this water is derived from the belief that there is a tendency in polluted waters toward the gradual death of the disease-producing organisms it contains—a belief that is firmly entrenched in the popular mind. The tendency is not always in this direction, the supposition that common water bacteria are more tenacious of life in infected water than the pathogenic organisms having been shown by some workers to be unfounded. Konradi[a] has shown that far from being unfavorable to their growth, water is an excellent medium for the culture of many disease-producing bacteria, and that in the long run it is they which survive over the water bacteria. The work of Mez[b] showed that these organisms live longer in sterilized than in dirty water, and that therefore pure drinking water once infected is more dangerous than foul water, a conclusion in line with the findings of Frankland and Klein, previously quoted. From this statement as a beginning, Konradi proceeded to experiment with the anthrax bacillus and its spores, *Staphylococcus pyogenes aureus*, the organism of pus, and the typhoid bacillus, all of the highest importance in this connection. He found that the ordinary water bacteria multiplied greatly for a time after the introduction of the pathogenic organisms, and then began to die out, and that after varying periods, the foul water, being kept at room temperature, was found to contain pure cultures of the disease-producing organisms, which retained full virulence up to complete evaporation. For the anthrax bacillus and its spores the period of life varied from 264 to 816 days, the water bacteria in the medium having completely disappeared after three or four weeks. The pus organism was found in pure culture after two months, and retained its virulence for 508 days. The bacillus of typhoid fever showed a similar power of conquering the water bacteria, which lived in the medium for four months, at the end of which time the bacillus typhosus was in pure culture, living in ordinary tap water at room temperature for 499 days. What more evidence is needed of the ability of the organisms of water-borne disease to poison a water as far as drinking purposes are concerned for a long time, admitting the pollution to cease, instead of continuing hourly as in the cases under consideration? Even sterilized water is found to allow the growth of anthrax and typhoid bacilli; though not of the pus micrococci.

It remains only to correlate these facts with the long-admitted disease-transmitting properties of water to make it clear that cities on the Ohio River immediately below Pittsburg might as well mix a well-known poison with pure water and drink it as use the river water without purification. "Among the carriers of virus, water is, according to the present state of our knowledge, by far the most important."[c] "Not only is typhoid one of the leading causes of death in America, but the greater part of it is conveyed directly or indirectly through water."[d] This fact has been so long established not only by scientific workers in the laboratory, but by long and costly epidemics, all traceable to the pollution of city supplies by typhoid-fever dejecta, that it is unnecessary to go further into that question. The fact is clear that the water of Ohio River below Pittsburg contains so large a number of pathogenic bacteria as absolutely to prohibit its use for drinking in the raw state.

CHARTIERS CREEK.

Washington, Pa.—The first important tributary stream below Pittsburg is Chartiers Creek, which receives the drainage of Washington, Pa. (population about 12,000). The water supply of this town is obtained from filter wells on the banks of Chartiers Creek, mixed at times with spring water from gravity sources. The position of the wells seems

[a] Centralblatt für Bakt., 36, May 28, 1904.
[b] Mikroskopische Wasser Analyse, 1898.
[c] Curschman, H., Typhoid Fever and Typhus Fever, Philadelphia, 1901.
[d] Baker, M. N., Municipal Engineering and Sanitation, New York, 1902.

to indicate that they are drawing largely on ground water on its way to the stream and not from the creek itself. That this is not sufficient protection is shown by the very high mortality rate for 1902.

Typhoid mortality at Washington, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1895	75	....	4
1900	110	42	3
1902	158	61	14

Without fuller data it is not possible to speak with certainty of this supply. It certainly is of doubtful quality. A field assay is given below.

Canonsburg, Pa.—Canonsburg (population 3,000), below Washington, on the same creek, has a gravity supply from a spring-filled reservoir, supplemented by raw water from Chartiers Creek when the water company deems necessary. The field assay shows the practical identity of the water with that at Washington, so that it seems likely that creek water is used much of the time. The presence of typhoid infection in Washington sewage is undoubted, and the likelihood of its occurrence in the water supply of Canonsburg follows naturally. The use of Chartiers Creek water raw is therefore ill-advised and dangerous. No figures showing typhoid mortality at Canonsburg are available.

OHIO RIVER FROM M'DONALD TO BEAVER RIVER.

McDonald, Pa.—At McDonald, Pa. (population 3,000), which drains into Ohio River above Sewickley, there is a mixed supply of a highly unsatisfactory character from Raccoon Creek and from deep wells. The water shed of Raccoon Creek is not, so far as known, guarded in any way, and the tap water is nearly always more or less turbid. The field assay shows a highly mineralized product, the carbonates being largely due to the well water, whereas the high turbidity and color show a surface origin from swampy drainage with inadequate sedimentation. It is not considered a good water for either domestic or industrial uses in its present condition.

Field assays of public supplies at Washington, Canonsburg, and McDonald.

[Parts per million.]

Determination.	Washington.	Canonsburg.	McDonald.
Turbidity	0	[a] 40	140
Color	96	180	140
Iron (Fe)	1.5	Trace.	0.5
Calcium (Ca)	107	110	142
Total hardness (as $CaCO_3$)	130+	130+	130+
Alkalinity	148	120	124
Sulphates (SO_3)	([a])	[a] 20	93
Chlorides (Cl)	7	36	59

[a] Estimated. [b] Slight trace.

Sewickley, Pa.—The greater portion of the population between Pittsburg and Sewickley (population 4,000) is supplied by the Monongahela Water Company, operating from Pittsburg. The Sewickley supply is derived partly by gravity from impounding reservoirs and partly from the Ohio River by pumping from cribs in the stream. The few analyses of the raw and the effluent water made in 1897 for the Pittsburg filtration commission show very little bacterial purification.

Analyses of public water at Sewickley.

[Parts per million.]

Date.	Water analyzed.	Turbidity.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Bacteria per c.c
1897.								
Nov. 3	Raw water........	Slight.....	0.110	0.016	None.	0.750	53.6	23,400
Nov. 3	Effluent...........	Clear.....	.325	.018	None.	1.500	37.4	910
Nov. 22	Raw water........	Slight.....	.210	.024	None.	.525	20.2	54,000
Nov. 22	Effluent...........	Slight.....	.080	.014	None.	.600	23.4	9,500
1898.								
June 27	Raw water........	Slight.....	.138	.046	None.	.525	24.0	15,500
June 27	Effluent...........	Slight.....	.140	.040	None.	.600	27.8	14,100

The figures for 1898 show that the degree of purification by this crib is uncertain and unreliable, and that the water supply from this source is not safe for domestic purposes. Typhoid-fever statistics confirm this view.

Typhoid-fever mortality at Sewickley, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1896	38	a 20	2
1897	33	a 20	2
1898	31	0	0
1899	47	7	3
1900	54	16	0
1901	53	11	3
1902	57	7	3
1903	49	10	2
1904	42	17	1

The percentages of deaths by typhoid fever are very high, as will be evident by reference to those of Olean and Salamanca, N. Y., and that of Bradford, Pa. The percentages of mortality from this disease at Allegheny, Pa., a notorious hotbed of typhoid fever, are as follows for certain years:

Typhoid mortality at Allegheny, Pa.

Year.	Total deaths.	Typhoid deaths.
1894	1,962	99
1896	1,995	74
1897	1,778	79
1898	2,036	73
1899	2,109	135

The two places are evidently in the same class, so far as the prevalence of typhoid fever is concerned. Certainly the water supply of Sewickley is not beyond suspicion. The experience of New Bethlehem, Pa. (see p. 26), a town of only half the size of Sewickley, shows that a filtration plant is not beyond the means of the latter if the citizens can be aroused to an appreciation of the loss annually suffered from this preventable disease.

Coraopolis, Freedom, and Monaca.—Besides Sewickley there are three or four other small towns between Pittsburg and Monaca, where Beaver River discharges into the Ohio. Coraopolis (population 3,000), a little above Sewickley, also pumps from a crib in the river. The quality of this supply is evident from the Sewickley figures. Freedom (population 2,000) also planned such a crib, but has succeeded in making arrangements with the filtration plant at Beaver Falls for a supply. Monaca (population 3,000) pumps its supply from deep wells in the gravel on the beach of the river. All these places sewer into the Ohio.

BEAVER RIVER BASIN.

SHENANGO RIVER.

Greenville, Pa.—Near the head of Shenango River, one of the tributaries of the Beaver, is the town of Greenville (population about 5,000). Its water supply is obtained by gravity from a spring-fed reservoir holding about 8,000,000 gallons. The daily consumption is about 1,000,000 gallons. In case of shortage the Little Shenango is pumped raw. This is a polluted stream and should not be used for drinking purposes without purification. The field assay (p. 83) shows that the water strikingly resembles those of French and Oil creeks. Arrangements should be made either for filtering the river water or for adding to the present storage capacity. Hardly any typhoid statistics are available for Greenville. In 1894 there were 7 cases and 1 death; in 1895 there were 15 cases and 1 death, enough to show that the cases were probably not isolated importations. The town sewage discharges into the creek.

Sharon, Pa.—About 20 miles down the Shenango is Sharon, with a population of about 10,000. The city water supply is derived from the river, the water being purified by mechanical filters, privately operated (see assay on p. 83). The plant consists of four large sedimentation tanks and eight filter units, the whole having a capacity of 1,700,000 gallons per day of fourteen hours. During the day the filtered water is pumped into the mains, whatever water is not used at the taps flowing into a 2,000,000-gallon storage reservoir. The field assay shows that the effluent from the filters is very similar to the raw water at Greenville.

The efficiency of mechanical filters is a matter of grave interest to many municipalities in this region, because of the very turbid condition of the stream waters. Although mechanical filtration has been practiced in this country for only a few years, it is very well understood that only by the coagulating processes in use as a preliminary to mechanical filtration can muddy waters be successfully handled day by day. Even if the small towns in this section could afford to install costly systems of slow sand filtration, it is probable that the high turbidities would soon so clog the filters as to make their operation very unsatisfactory. As the muddy stream waters are in this section the natural source of supply—at some places the only one—water purification has here developed largely along the lines of mechanical filtration.

When efficiently operated, with due study of the chemical nature of the water treated in each individual case, effluent water of satisfactory quality can be obtained from mechanical filters, the bacterial efficiency in many plants being nearly 100 per cent. When results are not satisfactory the cause of failure is usually found either in the inadequacy of the preliminary coagulation or in the grade of supervision provided. As the efficiency of the filters depends very largely on the complete combination of the suspended matters in the water with the chemicals added, failure may be expected unless each water is treated with the chemicals best suited to its composition and with a sufficient quantity of the chemicals. The majority of the processes devised for this purpose are in the experimental stage. The devices in most extensive use depend mainly on compounds of iron and aluminum. The processes depend upon the formation in the water of bulky precipitates through the combination of the aluminum or iron with the carbonates in solution. For this reason it is necessary to determine the alkalinity, and, if necessary, to increase an alkalinity naturally too low to allow the requisite chemical combinations. Ten or fifteen years ago, when the proc-

esses were not clearly understood, the coagulation basins were small and the amount of chemical added was frequently insufficient, so that a high degree of coagulation was seldom realized. In this respect the advance has been remarkable, the preliminary treatment receiving careful study, so that it is now very satisfactory. With the building of larger tanks, more complete chemical combinations are possible, so that a muddy water is very highly improved before going to the filters at all. Success depends so largely on the even uninterrupted flow of the chemical into the tanks that improvement in these filters has followed closely on improvement on the design of automatic devices for regulating the introduction of chemicals.

The second most common cause of failure of these filters is to be found in the grade of supervision provided. It would seem axiomatic that to install an expensive plant, designed to give certain results under carefully adjusted conditions, and then to hire an incompetent person to operate it is to make the machinery useless for the purpose for which is was designed. No business man would be guilty of such an absurdity with apparatus costing him the most trifling sum, yet such has been the course of action of many municipalities.

A most striking example of the efficiency of mechanical filtration of polluted surface waters is furnished by the decrease in the typhoid fever mortality of Lorain, Ohio, with the installation of filters. The town is located on the shore of Lake Erie, about midway between Cleveland on the east and Sandusky on the west, each about being 30 miles distant. The large amount of sewage that pours into the lake from these towns and others between them makes the raw water dangerous for a city supply unless taken out at a prohibitive distance from shore (cf. Erie, p. 104). The degree of healthfulness of this water supply before the introduction of the filter plant is clearly shown by the following figures showing mortality from typhoid fever:

Deaths per 100,000 from typhoid fever at Lorain, Ohio, before filtration.

Year.	Deaths.	Year.	Deaths.
1889	44	1893	183.3
1890	20	1894	48.8
1891	57	1895	131.6
1892	53	1896	83.3

These figures show that the supply ranked with the worst in the country at that time. In 1896 and 1897 mechanical filtration of this water by the Jewell system was resorted to. The figures showing typhoid fever mortality for the years following this installation are decisive as to the efficiency of the process in this instance:

Deaths per 100,000 from typhoid fever at Lorain, Ohio, after filtration.

Year.	Deaths.	Year.	Deaths.
1897	24.4	1900	11.5
1898	21.2	1901	5.5
1899	24.2	1902	26.3

The present mortality rate is as low as that of towns having carefully guarded surface supplies, and the filtration plant, judged by its practical results, is all that could be desired.

A chapter of important evidence is furnished by the rise in these figures when, in 1903, repairs to the plant made the use of raw lake water necessary for a brief period. For the first seven months of the year, the filter being then in use, there was not a single death from typhoid fever in the city; after the unfiltered water was turned in, although notices to the

public had been printed in the local papers, the death rate from this disease from August to November, inclusive, rose to 180 per hundred thousand, dropping to 60 per hundred thousand in December and practically disappearing soon after the raw water was shut off.[a] It is hardly possible to get a clearer demonstration of the value of such a system in safeguarding the public health. It may be said positively that no public supply in this section should be taken from surface waters without filtration. The population is too dense to permit of the segregation of drainage areas except at a prohibitive cost, and some of the cities are too large to be supplied by spring waters without extensive segregation. Accordingly it is found that the largest towns have installed filtration systems similar to that at Sharon.

Typhoid-fever statistics for Sharon are too few to establish anything except the presence of the disease in the years given. In 1894 there were 13 cases and 3 deaths; in 1898, 16 cases and 2 deaths—that is, about the same as Sewickley, though Sharon has three times the latter's population.

NESHANNOCK CREEK.

Mercer, Pa.—At Newcastle Beaver River receives the waters of Neshannock Creek, carrying the drainage of a number of small towns. Chief of these is Mercer (population 2,000), about 25 miles above Newcastle. The public supply is pumped from Otter Creek to a mechanical filter. A field assay is given on page 83. The high color of this water may be due to drainage from the Half-moon Swamp at the head of the creek. The drainage area of the stream is sparsely inhabited, but there is sufficient pollution to make filtration necessary. There is little public interest in the question of water supply.

Newcastle, Pa.—Newcastle (population 35,000), a large manufacturing town, has a mechanical filter plant. The water is pumped from Neshannock Creek to large sedimentation tanks, thence to 8 filter units. The plant appears to be efficiently conducted. The following analyses of raw and filtered water at this place were made by Dr. F. E. Witherell for the American Waterworks and Guarantee Company, which controls this plant and numerous others. They are furnished through the kindness of that corporation.

Analyses of raw and filtered water from Newcastle, Pa.[b]

Date.	Bacteria per cubic centimeter.		Efficiency.	Colon bacillus.[c]	
	Raw water.	Filtered water.		Raw water.	Filtered water.
1902.			*Per cent.*		
May 1	760	36	95	....	....
May 2	740	38	95	....	....
May 3	670	30	95	....	....
May 4	710	19	97	....	....
May 5	720	41	94	....	....
May 6	980	43	96	....	....
May 7	770	38	95	....	....
May 8	530	35	93	....	....
May 9	420	28	93	....	....
May 10	630	30	95	....	....
May 11	420	24	94	....	....
May 12	370	22	94	....	....
May 13	610	32	95	....	....
May 14	560	40	93	....	....
May 15	550	33	94	....	....
May 16	600	33	94.5	....	....
May 17	610	34	95	....	....
May 18	530	37	93	....	....

[a] Engineering News, 1894. [b] All analyses made by Doctor Witherell. [c] + positive; − negative.

Analyses of raw and filtered water from Newcastle, Pa.—Continued.

Date.	Bacteria per cubic centimeter.		Efficiency.	Colon bacillus.	
	Raw water.	Filtered water.		Raw water.	Filtered water.
1902.			*Per cent.*		
May 19	470	23	95	....	....
May 20	770	48	94	....	....
May 21	730	41	94	....	....
May 22	550	21	96	....	....
June 1	2,000	70	96.5	+	−
Do	1,200	40	97	+	+
June 2	1,100	37	97	+	−
Do	1,400	80	94	+	+
Do	900	54	94	+	+
June 3	1,200	36	97	+	−
Do	600	68	89	+	+
Do	1,060	44	96	+	+?
Do	1,100	42	96	+	−
June 26	45,000	112	99.75	+	....
June 29	15,000	127	99.2	....	....
July 2	12,000	86	99.3	....	−
July 4	24,000	93	99.6	....	−
July 6	8,500	93	99.9	....	−
1903.					
Aug. 15	1,205	20	98.3	−	−
Aug. 22	2,500	74	97	+	−
Aug. 27	9,000	85	99.1	+	−
Sept. 1	2,300	35	98.5	+	−
Sept. 4	8,000	27	99.7	+	−
1904.					
Aug. 10	1,260	20	98.4	+	−
Aug. 11	780	23	97	+	−
Aug. 12	1,620	21	98.6	+	−
Aug. 13	2,800	10	99.6	+	−
Aug. 14	3,200	15	99.5	+	−
Aug. 15	4,200	18	99.6	+	−
Aug. 16	3,320	5	99.8	+	−
Aug. 17	4,800	25	99.5	+	−
Aug. 18	3,130	10	99.7	−	−
Aug. 19	6,200	38	99.4	+	−
Aug. 20	4,200	8	99.8	+	−
Aug. 21	3,720	29	99.2	+	−
Aug. 22	3,120	43	98.9	+	−
Aug. 23	3,010	55	98.2	+	−
Aug. 24	2,760	2	99.99	+	−
Aug. 25	5,100	3	99.94	+	−
Aug. 26	6,600	8	99.9	+	−
Aug. 27	6,400	3	99.95	+	−
Aug. 29	3,900	2	99.95	+	−
Aug. 30	3,000	3	99.9	+	−
Aug. 31	3,800	3	99.92	+	−
Sept. 10	2,500	5	99.8	+	−
Dec. 26	2,000	15	99.3	+	−
Dec. 28	15,000	71	99.5	+	−
Dec. 31	21,500	450	98	+	−

Analyses of raw and filtered water from Newcastle, Pa.—Continued.

Date.	Bacteria per cubic centimeter.		Efficiency.	Colon bacillus.	
	Raw water.	Filtered water.		Raw water.	Filtered water.
1905.			*Per cent.*		
Jan. 5	4,760	54	99	+	−
Jan. 6	4,250	35	99.2	+	−
Jan. 7	3,950	21	99.5	+	−
Jan. 9	7,210	12	99.8	+	−
Jan. 11	3,100	6	99.8	−	−
Jan. 12	2,800	2	99.93	+	−
Jan. 13	5,220	9	99.9	+	−
Jan. 17	12,000	72	99.4	+	−
Jan 19	15,200	12	99.92	+	−
Jan. 24	5,600	20	99.6	+	−

The percentages of efficiency are calculated from the figures given and show marked improvement since 1902. For May of that year the efficiencies are low, averaging 94.5 per cent. For a water so grossly polluted as the Neshannock such an efficiency is not high enough to assure a reasonable immunity from disease, and the condition is reflected in the high typhoid-fever death rate for 1902, shown in the table below. For June, 1902, the average efficiency was 95.9 per cent, also a low figure. The figures for July show improvement if they represent average conditions. For 1903 the few figures given show an average efficiency of 98.5 per cent, which is much more satisfactory. The typhoid mortality in that year was so high as to suggest that at other seasons of the year the filters were not working so well. For 1904 the figures are fuller and show a percentage efficiency averaging $99\frac{1}{4}$ per cent, reflected in the 50 per cent decrease in typhoid deaths for 1904. The figures for 1905, so far as they go, seem to show that this high standard is being kept up; altogether the plant at Newcastle may be considered to be doing very good work at the present time.

In the foregoing table it is noteworthy that the colon bacillus was positively identified in the raw water in nearly every case where the test was made, and in the filtered water during 1902. Since then the results have been negative. Doctor Witherell made the following statement in a letter dated November 17, 1905:

The tests made for *B. coli communis* were as follows: For the first inoculation a glucose neutral red bouillon is used, made up of—

1,000 cubic centimeters distilled or soft water.
5 grams beef extract (Liebig's).
20 grams Witte's peptone.
$\frac{1}{10}$ gram Grubler's neutral red.
20 grams grape glucose.
1 gram sodium taurocholate.

Reaction is +1, Fuller's scale. The broth is inoculated with $\frac{1}{100}$, $\frac{1}{10}$, 1, 5, and 10 cubic centimeter water samples and incubated 24 to 30 hours at 104° F. If the presumptive test is positive—that is, if 30 to 70 per cent of gas is formed, approximately one-third being carbon dioxide, with the medium strongly acid to litmus, and the neutral red changed to canary yellow with green fluorescence—samples are plated into gelatin stab, agar streak, milk, potato, nitrates, Dunham's solution, and confirmatory results are looked for.

The typhoid statistics below are from the reports of the Pennsylvania State board of health, except for the years 1903, 1904, and 1905.

Typhoid mortality at Newcastle, Pa.

Year.	Population.	Deaths.	Rate per 100,000.
1895	19,600	16	....
1897	21,000	13	62
1898	24,000	6	25
1899	26,000	29	112
1900	28,350	36	127
1901	30,000	10	33
1902	32,000	39	122
1903 [a]	34,000	34	100
1904 [a]	35,000	18	51
1905 [a]	36,000	11	[b] 30.6

[a] Furnished by C. C. Honne, health officer of Newcastle.
[b] Up to Nov 11, 1905.

The figures showing population are roughly estimated from those for the census years 1890 and 1900. The estimates are only approximately correct, but are probably not far from the truth. As the number of cases is not obtainable for some years, the rate is calculated per 100,000 of population.

The field assays of this water show a very low alkalinity, probably due to acid drainage from manufacturing establishments on the stream. This is visible in the sulphate content also. The water is of fair quality for domestic purposes.

Field assays of public supplies in Shenango River and Neshannock Creek basins.

[Parts per million.]

Determination.	Greenville.	Sharon.	Mercer.	Newcastle.
Turbidity	0	0	0	0
Color	106	122	122	35
Iron (Fe)	1	.5	.5	Trace.
Calcium (Ca)	42	44	43	76
Total hardness (as $CaCO_3$)	47	47	42	61
Alkalinity	43	49	49	26
Sulphates (SO_3)	[a] 5	[a] 10	0	41
Chlorides (Cl)	5.6	11.2	9.7	9

[a] Estimated.

CONNOQUENESSING CREEK.

About 15 miles below Newcastle Connoquenessing Creek enters the Beaver near Ellwood City. The most important places in its drainage area are Butler, Grove City, Evans City, and Ellwood City.

Butler, Pa.—Butler (population 10,000), near the headwaters of Connoquenessing Creek, is well known to sanitarians for a noteworthy epidemic of typhoid fever occurring there a few years ago, caused by defects in the operation of the filters. The epidemic has been fully discussed by leading sanitarians, and in this place it is sufficient to remark that conclusive evidence was afforded by the costly experience of this period that the raw creek water was highly dangerous for drinking, and that constant vigilance in the operation of the filters is necessary to assure safety. The plant is now operated by the American Waterworks and Guarantee Company. Frequent bacterial analyses are made by Doctor Witherell, the coli tests being made as at Newcastle, except for the omission of the taurocholic acid control.

The Butler supply (see assay below) is undoubtedly the best of those examined in the Connoquenessing Creek drainage, as it contains far less mineral impurity than any other.

Evans City, Pa.—Evans City (population 1,200) is situated on Breakneck Creek, a tributary of Connoquenessing Creek. Its supply is obtained by gravity from a hill reservoir impounding spring runs. The high chlorides and alkalinity suggest the presence of ground water. This water probably contains calcium chloride and would corrode boiler tubes.

Field assays of public supplies in Connoquenessing Creek basin.

[Parts per million.]

Determination.	Grove City.	Ellwood City.	Butler.	Evans City.
Turbidity	0	[a] 20	0	0
Color	35	140	45	44
Iron (Fe)	2.7	1	0	1
Calcium (Ca)	119	67	28	94
Total hardness (as $CaCO_3$)	130+	66	39	66
Alkalinity	201	40	40	191
Sulphates (SO_3)	[a] 5	[a] 20	[a] 3	Trace.
Chlorides (Cl)	23	27	19	78

[a] Estimated.

Grove City, Pa.—Grove City (population 1,600) is situated on Wolf Creek, one of the headwater streams of Slippery Rock Creek, the most important tributary of Connoquenessing Creek. Its water supply is pumped from a 200-foot driven well to a standpipe. The field assay (above) shows the water to be of a fair quality for a ground water, although it is hard and contains a little more iron than usual. It gives satisfaction for drinking purposes, but would be wasteful for laundry uses and is so high in incrusting carbonates that it would certainly incrust tubes.

Ellwood City, Pa.—Ellwood City (population 2,500) draws its water supply from Connoquenessing Creek. The water is said to be mechanically filtered. Before entering the Ellwood supply the creek receives the sewage of Butler (population 10,000), Evans City (population 1,200), and the two small towns of Harmony and Zelienople. The water is undoubtedly too grossly polluted to be safe in its raw state.

The traces of sulphur and iron, shown in the field assay (above), are probably due to a little mine drainage. The turbidity is higher than it should be for a filtered water and casts grave doubt upon the efficiency of the process. The color of the water is also high.

It will be clear from the foregoing data that Beaver River drains much sewage pollution from this section of western Pennsylvania. Filtration of this water is absolutely necessary before it can be safely used as a public supply.

BEAVER RIVER.

Beaver Falls, Pa.—The largest city on Beaver River is Beaver Falls (population 10,000). At this point the supply was until 1900 obtained directly from the river without purification. The result of the use of such water is indicated by the following figures showing the typhoid-fever mortality, which is among the highest in the country:

Typhoid mortality at Beaver Falls, Pa.

Year.	Total deaths.	Typhoid cases.	Typhoid deaths.
1896	124	28	8
1897	134	105	11
1898	128	80	15
1899	138	27	8
1900	169	22	15

Figures for later years are unobtainable.

In 1900 mechanical filters were installed, supplying Beaver Falls, New Brighton, Rochester, Freedom, and other places. Four of the filters are of the Jewell type, the remaining four of the old closed or oil-tank type. The plant seems to be efficiently operated, and local physicians speak well of the decrease in the number of typhoid fever cases since its installation. Bacterial analyses of 20 samples collected at the intake and at a tap in Beaver Falls show an average bacterial content as follows:

Bacterial analyses of water at Beaver Falls, Pa.[a]

[Bacteria per cubic centimeter.]

Raw water.		Filtered water.		
Total.	B. coli.	Total.	B. coli.	Efficiency.
				Per cent.
246,850	195	29,300	12	94

[a] Data furnished by water company.

This is a low efficiency both for total organisms and for bacillus coli, yet the filtrate is very much better than the raw water.

The field assay (p. 87) shows a water typical of the river waters of this section. It is soft enough to be suitable for any purpose.

OHIO RIVER BETWEEN BEAVER RIVER AND FISH CREEK.

Below the mouth of Beaver River the Ohio flows nearly southwest for about 10 miles through a rolling farming country. It crosses the State line a few miles above Chester, W. Va., a little town of about 1,000 population. From this point on, notwithstanding the enormous pollution in the river, the water is very commonly used as a public supply in its raw state. It is evident from the foregoing discussion that the inevitable effect of such a practice is the sacrifice of many lives annually, with the additional waste of thousands of dollars by the communities affected. Although West Virginia has laws on its statute books forbidding stream pollution under penalty of $5 fine for each offense, there is wanton and wholesale contamination of every stream in the State. As no typhoid-fever statistics are obtainable for towns in this State, except for Wheeling, it is impossible to supply that concrete evidence of the disease-producing quality of the water which is furnished by such figures. The quality of these supplies will be evident, however, from the following descriptions of conditions in this section and from the typhoid-fever records of those towns in Ohio which take their supply from the river unpurified and which have collected figures concerning this disease:

Chester, W. Va.—At Chester the public supply is pumped from a filter well that is sunk in the fine sand of the river bank. The well is about 8 feet in diameter and is covered with a brick and concrete dome. The pumping machinery is mounted in a larger well close by, a gallery connecting the two. The effluent from this plant is beautifully clear and sparkling at all times, although the river is usually muddy. There can be no question, however, that so far as organic contamination is concerned no change of importance occurs during the natural filtration of this water. It can not be regarded as a safe supply for this municipality, and if typhoid-fever statistics were available the town would probably be found to suffer heavily from the disease. That this is not mere conjecture is evident from the high typhoid-fever percentages for East Liverpool, Ohio, directly across the river. This town pumps its water supply from the Ohio River raw, and is seen to be suffering constantly and heavily from typhoid fever.

Typhoid mortality at East Liverpool, Ohio.

Year.	Total deaths.	Typhoid deaths.
1897	154	9
1900	196	17
1901	187	26
1902	226	15
1903	337	13

The field assay (p. 87) shows the increased mineral content resulting from the passage of the water through the river sand, the mineral contents being appreciably higher than those of the river water at Pittsburg. This water is too hard to be considered excellent for boiler uses, and its muddy condition in the raw state makes it very poor for other industrial purposes. It is, however, of better quality than the ground waters in this section, as will be evident from the field assay of the wells at Wellsburg and Wheeling, given below.

New Cumberland, W. Va.—At New Cumberland, about 15 miles below East Liverpool, the city supply is also raw Ohio River water. The town has about 1,200 inhabitants, and is partially sewered. Above it on both banks of the river are visible evidences of pollution, besides the accumulated filth coming down in the river from Pittsburg. The supply of Steubenville, Ohio (population, 14,000), is of the same kind. The officials of this town have for years made no report of typhoid mortality.

Wellsburg, W. Va.—Wellsburg (population, 2,500), about 10 miles below Steubenville, also uses raw Ohio River water. The field assay of water from a 60-foot well much used for drinking purposes on one of the main streets of Wellsburg is given on page 87. There are are numerous drilled wells on the the streets, to which resort is had for drinking water to some extent. This water is very hard and not suitable for any use except drinking.

Wheeling, W. Va.—Wheeling (population, 40,000), on Ohio River about 14 miles below Wellsburg, has probably one of the worst typhoid-fever records for a town of its size and wealth in this or any other country. Like the towns just mentioned, it pumps its supply raw from Ohio River, without any attempt even at adequate sedimentation. Wheeling Creek, which flows through most of the town, is an open sewer. The intake of the waterworks is located a very short distance above the town. The works are owned by the city, and considerable thought has been devoted to the regulation of rates, but none to the quality of the water supply. In view of the conditions above described, under which town after town turns its disease-polluted sewage into the river, the strange thing is not that Wheeling should lose many lives and thousands of dollars through the use of polluted water for drinking, but that any American community should tolerate such a state of affairs. The figures shown below are available from the reports of the United States Public Health and Marine-Hospital Service. Although for but a portion of the years shown, they indicate closely the character of the supply:

Typhoid mortality at Wheeling, W. Va.

Quarter ending—	Total deaths.	Deaths from typhoid fever.
March 31, 1904	200	8
June 30, 1904	187	18
March 31, 1905	182	7
June 30, 1905	141	8

The significance of these percentages may be better understood when they are compared to the figures previously given as to Sewickley, Allegheny, Pittsburg, McKeesport, and other places. The condition here is almost incredibly bad.

The field assays below shows that the river water is considerably softer than the naturally filtered water at Chester. The well of the Acme Box Company is used for all purposes, both steam making and drinking, in the factory of the concern. It is unfit for any of them, being so excessively high in sulphates and iron as to corrode boiler tubes very rapidly. The use of this water represents a heavy annual expense for needless repairs. It is not very palatable, and its high color is not reassuring as to the safety of the well from contamination by surface water.

Moundsville, W. Va.—At Moundsville (population, 6,000) the water supply is obtained from wells on an island in Ohio River of the rather rare type in use at Gallipolis, Ohio, described on page 64. The typhoid-fever statistics of the latter town may very well be applied to the consideration of Moundsville's supply, the conditions being practically identical at the two places. The wells are four in number and 16 feet deep. The borings are carefully cased, admitting water only through strainers at the bottom. They are connected near the top so as to be pumped together. The effluent is beautifully clear and pleasant to the taste. The field assay shows considerable diminution of the sulphates in the river water, with entire absence of suspended matter and color, though at this period the raw water is a muddy brown.

Field assays of water from towns along Ohio River.

[Parts per million.]

Determination.	Beaver Falls, Pa., public supply.	Chester, W. Va., public supply.	Wellsburg, W. Va., 60-foot well.	Wheeling, W. Va., well of Acme Box Co.	Wheeling, W. Va., city supply.	Moundsville, W. Va., city supply.
Turbidity	0	0	0	0	0	0
Color	83	90	5	123	45	0
Iron (Fe)	([a])	Trace.	.5	20	([b])	0
Calcium (Ca)	45	102	200	274	55	96
Total hardness (as $CaCO_3$)	51	128	....	....	77	111
Alkalinity	29	88	267	380	22	63
Sulphates (SO_3)	[c] 20	40	54	+522	41	15
Chlorides (Cl)	12	27	15	99	19	24

[a] Slight trace. [b] Very slight trace. [c] Estimated.

FISH CREEK.

Fish Creek, which enters the Ohio about 8 miles below Moundsville, drains a country very deficient in water resources. Along the West Virginia Short Line of the Baltimore and Ohio Railroad the small communities have to get their supplies from individual wells, the deep-well water not being of very good quality.

Hundred, W. Va.—At Hundred (population, 300) there is a 118-foot well, which, as shown by the field assay, is of very good quality for water drawn from such a depth. The high alkalinity may indicate the presence of magnesium. Although somewhat hard, this water would make a good public supply.

Littleton, W. Va.—Littleton (population, 700), a few miles farther west, has a public supply very similar in quality to the well at Hundred. It is drawn from 2 wells 145 feet deep recently drilled to replace the public supply from Fish Creek, a little stream which is probably as highly polluted for its size as any stream could be. The springs in this section are not very numerous nor very large, most of them drying up in the summer. The Farrell Spring at Littleton, a limestone spring of unusual hardness, is piped into a few dwellings for domestic purposes. Its water is strikingly similar in mineral content to that of the deep well.

Board Tree and Cameron, W. Va.—The Bill Spring at Board Tree (population, 50), a few miles west of Littleton, is also very hard, the water seeming to come from a limestone

formation. It is much used for domestic purposes. The 66-foot well at Board Tree is the only bored well in this section. Its water is so high in incrusting solids as to be of no use except for drinking. Fish Creek itself is a small stream that flows over the naked rock in most of its course and practically dries up in the summer. The field assay shows that its water is considerably harder than the river waters of the Monongahela basin, but still comparatively soft and available for industrial purposes. The railroad leaves the stream soon after passing Board Tree, going north to the terminus at Moundsville. The only important town in this section is Cameron, which has about 1,000 population. It has a city water supply pumped to reservoirs from 5 driven wells 100 feet deep. The field assay shows this water to be far too hard for any use except drinking, the sulphates being so high as to incrust boiler tubes. The railroad uses the waters of Graves Creek, a small stream emptying into Fish Creek, for steaming purposes. A large brick filter well has been constructed in the bank of the stream, in which the water is collected. The field assay shows it to be but little better than the well water.

Field assays of waters in Fish Creek basin.

[Parts per million.]

Determination.	Hundred.		Board Tree.		Littleton.		Cameron.	
	118-foot well.	Fish Creek.	Bill Spring.	66-foot well.	Farrell Spring.	145-foot well.	100-foot wells.	Graves Creek.
Turbidity	0	0	0	0	0	0	0	[a] 4
Color	5	37	35	96	35	90	17	10
Iron (Fe)	.75	0	0	1.75	0	.8	.5	0
Calcium (Ca)	70	32	87	156	110	119	137	102
Total hardness (as $CaCO_3$)	118	63	118	....	130+	132	130+	132
Alkalinity	187	35	61	171	78	71	216	47
Sulphates (SO_3)	20	5	30	58	35	42	83	52
Chlorides (Cl)	19	14	14	80	24	19	49	19

[a] Estimated.

FISHING CREEK.

At New Martinsville another small stream, Fishing Creek, enters the Ohio, draining also a poor and sparsely populated country. The industry of this section has always been dependent on the oil wells, and the decline or failure of these has caused the abandonment of many habitations.

Smithfield, W. Va.—Smithfield, near the crest of the divide between the Monongahela and the Ohio, is a typical oil town of a few hundred population, without any public water supply. The 160-foot well assayed is one of three 8-inch wells bored by the South Penn Oil Company for boiler uses and also for town supply. It yields a surprisingly soft water, the total hardness not being much higher than that of Fish Creek. The chlorides, however, are so enormously high as to make the water very corrodant in boilers (see assay below). It is probably best used for drinking only. A sample from a 46-foot well showed a total hardness of 91 as compared with the 42 parts per million of the last supply, so that in this instance it is not necessarily the deep-well water that is harder. There are very few permanent springs in this section. The water of Carlin Spring (see assay below), which is 80 feet above the house into which it is piped, is of fair quality, the total hardness, it is noted, being exactly the same as that of the shallow well.

Pine Grove, W. Va.—At Pine Grove, about 10 miles west of Smithfield, a once prosperous oil town, having at present about 500 population, there is no public supply, the townspeople using individual wells and small springs. The 50-foot well shown in the assay is probably high in magnesium carbonate and the alkalies. It is of fair quality for domestic purposes. The Newman Spring is much better in every respect, but is not large enough to supply more than a few families.

Field assays of water at Smithfield and Pine Grove, W. Va

[Parts per million.]

Determination.	Smithfield.			Pine Grove.	
	46-foot well.	160-foot well.	Carlin Spring.	50-foot well.	Newman Spring.
Turbidity	....	0	0	0	0
Color	....	35	96	17	37
Iron (Fe)	....	Trace.	0	0	0
Calcium (Ca)	....	(a)	46	32	35
Total hardness ($CaCO_3$)	91	42	91	77	63
Alkalinity	....	236	49	229	47
Sulphates (SO_3)	....	0	(a)	0	0
Chlorides (Cl)	....	393	19	90	9

[a] Very slight trace.

OHIO RIVER FROM FISHING CREEK TO MIDDLE ISLAND CREEK.

New Martinsville, W. Va.—New Martinsville (population, 2,000) has expended much money in experimenting with water-supply methods without adequate return. Its supply is now pumped raw from Ohio River. An attempt was made to get water from filter wells similar to those at Moundsville, but unsuccessfully. Recently it has been planned to dig large brick wells in the shore of the river and pump the public supply therefrom. This would give a very clear water satisfactory for industrial purposes, but it would be no safer from a sanitary standpoint than the raw water itself. The condition of Ohio River is well recognized in this town, which has gone to the length of providing a number of drilled wells scattered over the city, from which pure drinking water is obtainable. The field assay shows this water to be extremely hard, but it should be excellent for drinking.

Sisterville, W. Va.—The only important town between New Martinsville and St. Marys, about 35 miles down the river, is Sisterville, a manufacturing town which had a population of 3,000 in 1900 and which is growing with great rapidity. Its supply is pumped directly from Ohio River to tanks.

St. Marys, W. Va.—The public supply at St. Marys (population, 1,000) is also pumped raw from Ohio River. The high turbidity of the sample indicates that the inhabitants of this town are practically drinking diluted mud for a large part of the year. The water of the 60-foot well at this point seems to be of good quality for drinking, although somewhat hard. The high hardness as compared to the calcium content would seem to indicate that the alkalinity is due mostly to magnesium carbonate. The town is built directly on the river and contributes liberally to its pollution.

Field assays of water at New Martinsville and St. Marys, W. Va.

[Parts per million.]

Determination.	New Martinsville.		St. Marys.	
	Ohio River.	53-foot well.	Ohio River.	60-foot well.
Turbidity	140	0	240	0
Color	88	22	35	35
Iron (Fe)	1	5	0	(a)
Calcium (Ca)	64	200	47	60
Total hardness ($CaCO_3$)	76	....	97	130+
Alkalinity	35	203	32	42
Sulphates (SO_3)	[b] 20	[b] 10	[b] 20	0
Chlorides Cl)	19	40	29	29

[a] Slight trace. [b] Estimated.

MIDDLE ISLAND CREEK.

Middle Island Creek, which discharges into the Ohio a little above this point, drains a sparsely populated farming country. As far as contamination goes, however, the scattering nature of the population is more than counterbalanced by the directness of the pollution. In nearly every case where it was possible and convenient to build a privy on or close to the creek it has been built there instead of where it would not pollute the water.

West Union, W. Va.—The only important town on this drainage area is West Union, on the Parkersburg division of the Baltimore and Ohio Railroad, about 30 miles west of Clarksburg. The assay below shows the water of the creek to be of very fair quality for industrial purposes. The high color is due mostly to organic pollution. West Union (population, 1,200) has no public supply, the inhabitants getting their water from wells varying in depth from 20 to 150 feet. The 128-foot well assayed (below) is in very general use, being on the public street. The water is of poor quality for any purpose except drinking. That of the 38-foot well is strikingly similar in its mineral contents.

OHIO RIVER FROM MIDDLE ISLAND CREEK TO THE LITTLE KANAWHA.

Williamstown, W. Va.—Williamstown (population, 400), on Ohio River, about 15 miles below St Marys has no public supply. The field assay shows that the water from a 60-foot well at this place is of fair quality though somewhat hard. It is noteworthy that the field assay of Ohio River at this point shows exactly the same chlorine content. The well is about 300 feet from the river.

Field assays of water from West Union and Williamstown, W. Va.

[Parts per million.]

Determination.	West Union.			Williamstown.	
	Middle Island Creek.	128-foot well.	38-foot well.	60-foot well.	Ohio River.
Turbidity	0	0	0	0	0
Color	160	0	17	22	22
Iron (Fe)	0	(a)	.5	0	0
Calcium (Ca)	Trace.	126	133	87	46
Total hardness ($CaCO_3$)	63	130+	....	139+	139+
Alkalinity	36	116	0	42	29
Sulphates (SO_4)	(b)	[c] 20	[c] 20	44	[c] 20
Chlorine (Cl)	9	90	70	40	40

[a] Slight trace. [b] Very slight trace. [c] Estimated.

Marietta, Ohio.—Opposite Williamstown is Marietta, with about 15,000 population, discharging its sewage into the river. Three streams in Ohio—Little Muskingum River, Duck Creek, and Muskingum River—enter Ohio River within a mile or two of each other at Marietta. Each drains an area comprising considerable population, so that the sewage entering at Marietta alone would be sufficient to make the raw river water unsafe, even if the pollution entering above were eliminated.

Parkersburg, W. Va.—In spite of the pollution at Marietta, which is evident from a cursory inspection of the river, Parkersburg, otherwise a growing and progressive town (population, about 17,000) takes its water supply unpurified from Ohio River. The supply is extremely bad, being almost always very turbid and unsatisfactory for any domestic uses. The claim is made in the city that this water is used only for fire purposes, spring water being largely bottled and sold for drinking. The value of this claim has already been estimated. There is no doubt that if typhoid-fever statistics were obtainable for this city a very serious condition of the public health would be manifest. It may be very well esti-

mated from the typhoid-fever statistics of Marietta, Ohio, except that conditions at Parkersburg would be much worse.

Typhoid mortality at Marietta, Ohio.

Year.	Total deaths.	Typhoid deaths.	Year.	Total deaths.	Typhoid deaths.
1897	115	7	1901	256	21
1898	123	6	1902	174	13
1899	163	5	1903	194	8
1900	192	10			

These percentages are so high as to need no comment. Both Marietta and Parkersburg have the distinction of being in the same class with Wheeling as to water supply.

Of great interest in this connection are the filters of the Parkersburg Steel and Iron Company a few miles above the city. These wells are about 13 feet in diameter, 34 feet deep, and about 75 feet from shore. They are bricked up from the bottom, the pumping machinery being incased in one of the wells, which is connected with the other. Six hundred thousand gallons of clear water are pumped from these wells every day, although the Ohio River water is usually muddy. It is found quite satisfactory in the boilers of the company, but it is hardly necessary to say that in spite of its brilliancy and inviting appearance it would not be safe for drinking. The well on the public street in Parkersburg is one of two or three that are much drawn on for drinking purposes. The water is utterly unfit for anything else, being very high in sulphates and chlorides (see assays below).

Field assays of water from Ohio River and well at Parkersburg.

[Parts per million.]

Determination.	Raw water.	Filtered water.	Well water.	Determination.	Raw water.	Filtered water.	Well water.
Turbidity	180	0	0	Total hardness $CaCO_3$.	76	139+	....
Color	90	45	5	Alkalinity	27	100	42
Iron (Fe)	([a])	0	.5	Sulphates (SO_3)	[b] 20	[b] 20	144
Calcium (Ca)	50	142	137	Chlorides (Cl)	19	19	101

[a] Slight trace. [b] Estimated.

LITTLE KANAWHA RIVER BASIN.

A great deal of drainage enters the river at Parkersburg by way of Little Kanawha River, which flows nearly west across the State from Upshur County. The principal tributary of the Little Kanawha is Hughes River, which enters at Newark station.

LITTLE KANAWHA RIVER.

There are several small towns on this stream, the largest being Glenville (population, 400), Grantsville (population, 300), Spencer (population, 900), Reedy (population, 400), and Elizabeth (population, 800), comprising a total urban population of 2,500, all of which contribute privy pollution to the stream. The water of Little Kanawha River is one of the purest in the State so far as inorganic content goes, being so soft as to rank with the Pennsylvania spring waters. The field assay at Burnsville, not far from its source, shows a very excellent water. The field assay of water from Little Kanawha River at Parkersburg shows a complete change in its character. The turbidity at the mouth of the stream is very high at all times on account of the character of the soil through which it flows in the lower half of its course. It gains very much in hardness also, and is altogether undesirable in its raw state for domestic use at Parkersburg, although soft enough to be of fair quality for boilers.

HUGHES RIVER.

Pennsboro, W. Va.—Pennsboro (population, 800) has no public supply, the inhabitants using individual wells, which are few and yield water of poor quality. The 207-foot well assayed below is too high in mineral content to be of use for any purpose, there being too much calcium to be correctly estimated by field methods and a qualitative test showing the presence of much magnesium. The water of the 46-foot well is somewhat better in quality, but only by comparison. Both these wells are subject to shortage in dry times. The town is built on steep slopes, draining into the North Fork of Hughes River, privy contamination being conspicuous, and the same is true of the other small stations along the stream.

Cairo, W. Va.—The most conspicuous carelessness in public supply in this section is at Cairo (population 800). This town pumps its supply from Hughes River, the claim being made that it is only for fire protection, and that drinking water is taken entirely from individual wells. About 100 feet above the pumping station on the creek are a privy and barn right on the banks of the stream, so that at high water filth from both places goes directly into the river and heavy rains at all times wash pollution into the stream. This is a representative condition in this section. Field assay below shows the creek water to be of fair quality for industrial purposes, the well water not so good. It seems probable that the calcium is present almost entirely as calcium chloride, the alkalinity being extremely low. The color of this well water is so high as to create a suspicion as to its freedom from contamination.

Field assays of water from Little Kanawha River basin.

[Parts per million.]

Determination.	Pennsboro.		Cairo.		Burnsville.	Parkersburg.
	207-foot well.	46-foot well.	40-foot well.	Hughes Creek.		
Turbidity	0	0	0	Cloudy.	0	150
Color	35	17	44	244	70	35
Iron (Fe)	(a)	0	2	(b)	Trace.	(a)
Calcium (Ca)	High.	130	130	61	0	15
Total hardness (as $CaCO_3$)	139+	139+	132	76	28	104
Alkalinity	424	185	26	41	23	34
Sulphates (SO_3)	c 10	0	0	0	0	(a)
Chlorides (Cl)	60	40	172	40	9	40

a Slight trace. b Very slight trace. c Estimated.

OHIO RIVER FROM LITTLE KANAWHA RIVER TO KANAWHA RIVER.

Between Parkersburg and Point Pleasant there is no important city on the Ohio River. Little places having a hundred or more inhabitants are dotted along the stream, the largest being Ravenswood and Millwood, which are the termini of short branch lines of railroads. Neither have public supplies.

Point Pleasant, W. Va.—Point Pleasant (population 2,500) has a water supply of the natural filtration type in use at Gallipolis, Ohio, and Moundsville, W. Va. It is derived from two wells drilled in the Ohio River sand, the water seeping through the sand and entering the wells through strainers at the bottom. It is pumped into the city reservoir by compressed air. The water is of crystal clearness and low temperature in summer, so that it is very inviting and much used. The experience of Gallipolis would indicate that for a year or two this will be an ideal supply, but it is doubtful whether it will be safe for drinking a few years hence. Comparison with the raw river water shows high turbidity eliminated by the natural filtration and some gain in mineral content by the passage through sand. Except for its muddiness the raw water is much more desirable for industrial purposes.

Field assays of Ohio River water from Point Pleasant, W. Va.

[Parts per million.]

Determination.	Filtered.	Raw.	Determination.	Filtered.	Raw.
Turbidity	0	429	Total hardness (as $CaCO_3$)	118	83
Color	17	....	Alkalinity	124	47
Iron (Fe)	0	....	Sulphates (SO_3)	[a]20	[a]20
Calcium (Ca)	98	82	Chlorides (Cl)	15	....

[a] Estimated.

KANAWHA RIVER BASIN.

Kanawha River has a drainage area about as large, roughly, as that of the Monongahela. It drains nearly all the southern half of West Virginia. The principal industries of the country through which it flows are coal mining and lumbering, but the latter is rapidly disappearing. Typhoid-fever statistics are hardly necessary in this drainage area. Ocular evidence of the pollution of the surface waters is so plentiful on all sides that the mere description of conditions is enough to condemn nearly every supply in the section.

The principal tributaries of the Kanawha are Gauley, Greenbrier, and New rivers, the last being really the Kanawha under a different name.

NEW RIVER BASIN.

New River has its rise in North Carolina and enters West Virginia at its southern boundary. It flows through a beautiful mountain country, sparsely inhabited, and is comparatively unpolluted until it receives the waters of Bluestone River.

BLUESTONE RIVER.

Bluestone River is a very small stream, draining a number of mining camps and flowing into New River about 5 miles above Hinton. Field assays at Pocahontas, Va., and Graham, Va., (p. 93), show the presence of a great deal of free acid in the mine effluent waters, probably not, however, in sufficient quantities to be germicidal, even if the flow of both were constant. It is noteworthy that all along this stream algæ flourish, apparently unharmed by the acid. The disgusting pollution by privies in this section is therefore carried down practically unchanged, except for the worse, into New River. Pl. V, *B* gives a fair idea of sanitary conditions at the head of this stream at low water. The place pictured is by no means the worst on the course of the stream. It is evident that rain at all times washes privy droppings into the stream, and that at high water the contents of the privies find their way directly into the current. The population of this town is largely composed of colored coal miners, who live herded together along the banks in squalid huts, under the most unsanitary conditions. Typhoid-fever dejecta poisoning this water from these people would have ample time to be carried down for many miles before the case would even be brought to a physician for treatment.

Graham, Va.—Good water is scarce in this section. The 52-foot well at Graham, Va. (population 1,500), shows very hard water, unsuitable for domestic use, yet it is considered one of the best in the town. The water stratum from which this well draws has apparently been contaminated by a cesspool sunk a few hundred feet above the well. A sample recently sent to the State University at Morgantown, W. Va., for analysis is said to have shown the presence of intestinal pollution.

Pocahontas, Va.—The public supply of Pocahontas (population 2,800) is obtained from Bluestone River, which is also pumped by the Norfolk and Western Railroad to supply its shops at Bluefield and its station at Graham. The partial field assays show results of qualitative tests for sulphuric acid in Baby mine drainage at Pocahontas, Va., and quantitative determinations of iron and sulphates.

Field assay of water of Bluestone River at Pocahontas, Va.

[Parts per million.]

Determination.	Laurel Creek above mine waste.	Outfall at mouth.	1,000 feet below mine outfall.	3,000 feet below outfall.
Iron (Fe)	2	4	3	3
Alkalinity	(a)	(b)	(c)	Acid.
Sulphates (SO_3)	122	+522	338	410

a Water acid. b More acid. c Much more acid.

Bluefield, W. Va.—The public water supply of Bluefield (population 7,000), on Brushy Fork, forms an exception to the general filthy character of the water supplies in this section. The supply is derived from two large springs a few miles above town, which are carefully walled up and protected against pollution, accidental or otherwise. The supply is always abundant and seems to be of good quality, though a little hard for laundry uses. The high color is a little disquieting, but may be due to marshy drainage or a foul condition of the pipes. It is undoubtedly the best water in this section. The water of the deep wells at the brewery, one of which was assayed, is very much harder and contains an appreciable amount of sulphates. It is used for steam making at this establishment and causes considerable trouble in the boilers, as might be expected.

Field assays of water from Graham, Va., and Bluefield, W. Va.

[Parts per million.]

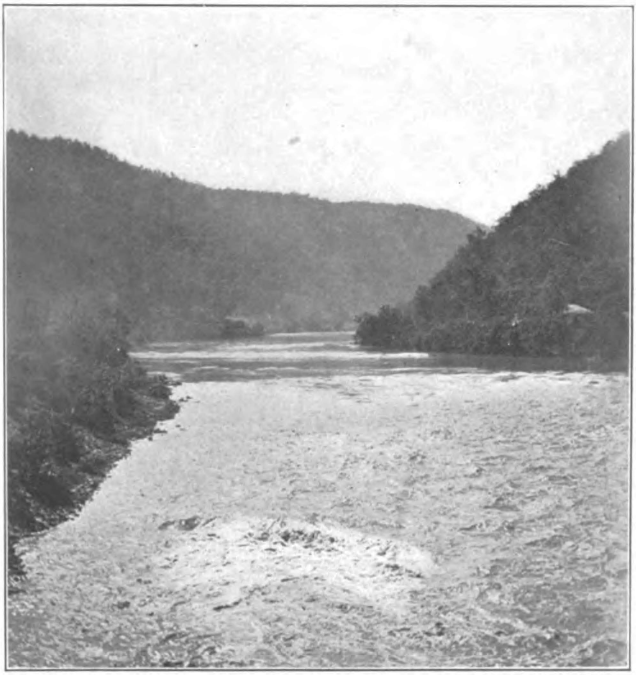
Determination.	Graham, Va., 52-foot well.	Bluefield, W. Va.	
		Public supply.	700-foot well.
Turbidity	0	0	0
Color	10	122	....
Iron (Fe)	.5	0	(a)
Calcium (Ca)	130	113	146
Total hardness (as $CaCO_3$)	....	111	....
Alkalinity	147	121	269
Sulphates (SO_3)	b 10	b 5	42
Chlorides (Cl)	24	9	21

a Very slight trace. b Estimated.

GREENBRIER RIVER.

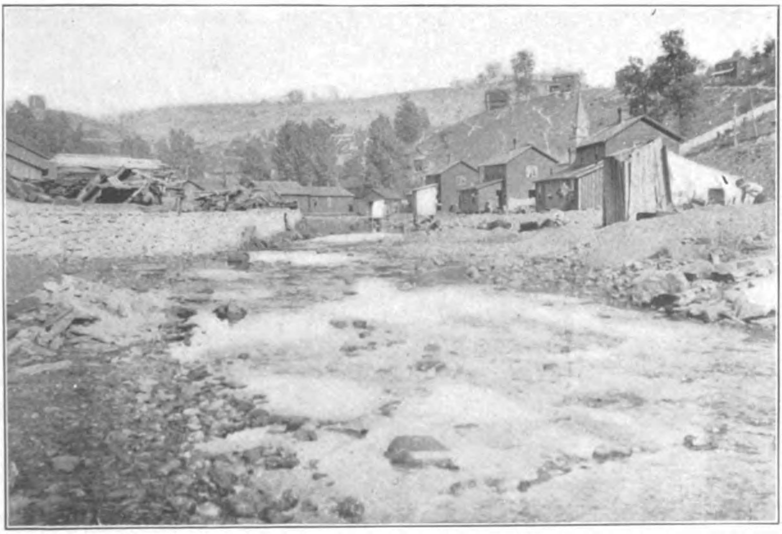
At Hinton, New River receives an enormous amount of pollution from Greenbrier River, an important tributary, on which the conditions are very unfortunate. It is one of the most beautiful streams in the State, the water almost always being very clear, but it is poisoned at its very source by privy contamination.

Durbin, W. Va.—Above Durbin, on the headwaters of the stream, there are a great many sawmills. Sanitation in these mill camps consists in building the privies directly over the river and in throwing all waste and refuse either into the stream or on the ground near by, so that they can be washed into the water. At Durbin fecal pollution is nauseatingly abundant on the banks. The railroad privy is so located as to discharge into the river, and a number of the houses drain almost directly into a small run that enters the river at this point. More heedless contamination of a pure and beautiful river could hardly be imagined. The field assay (p. 95) shows a water of almost perfect purity, its high color being the only objec-



A. CHARACTERISTIC VIEW ON NEW RIVER, WEST VIRGINIA.

Showing rapid flow.



B. HEAD OF BLUESTONE RIVER, WEST VIRGINIA.

Showing existing conditions.

tionable feature. The water of the 84-foot well at this place is of fair quality, not too hard for laundry use.

Marlinton, W. Va.—Between Durbin and Marlinton the contamination from mill camps is as bad as above Durbin. Marlinton, the largest hamlet in this section, is a pretty and rapidly growing lumber town of about 500 population. It has no public water supply. Greenbrier River at this point shows an increase in hardness, but is still a very soft water (see table below). The pollution at Marlinton from outhouses is considerable. A quasi public supply is piped into the railroad tank, and thence into a few buildings, from Knapp Creek, a little trout stream, comparatively clean and pure. The field assay shows the Knapp Creek water to be of excellent quality for any purpose. Still better is the water of the large spring that is piped to two banks and a boarding house in the town. There is practically no mineral impurity in this water except the iron. The high color is probably due to the nature of the drainage. It is the best supply in this section.

Ronceverte, W. Va.—Between Marlinton and Ronceverte (population about 1,000) there is a scanty population and but little drainage from houses. It is unfortunate, however, that at almost every place where there is a house a privy either overhangs the stream or stands close to it. The Ronceverte water supply is pumped directly from Greenbrier River into a reservoir, whence it flows by gravity into the mains. It is used unpurified for all purposes, and the townspeople regard it as pure water, because there are no houses directly above the intake. In the light of the above discussion of Allegheny and Monongahela rivers it is plain that self-purification in this stream is a negligible factor. While by no means an unusually rapid stream, it is too small for navigation, and its occasional pools are separated by numerous stretches of swift water. It is so grossly polluted from its very source to a point a mile or two above the pumping station as to leave no doubt of its unhealthfulness when used raw as a public supply. Ronceverte is not sewered, and its drainage and that of the railroad shops at this point form an important contribution to the river.

Alderson, W. Va.—At Alderson, about 8 miles below Ronceverte (population 800), there is no public supply. The water of the 80-foot well (assay below) is a typical ground water of this locality. Although very hard, it is a good water for drinking, the well being carefully cased into the rock. There is much defilement of the river at this point from outhouses.

Talcott, W. Va.—At Talcott, a hamlet of a few families, 10 miles above Hinton, some privies overhang the river. Dejecta from these drop directly into the river, and could certainly infect supplies below in a few hours.

Field assays of water from Greenbrier River basin.

[Parts per million.]

Determination.	Durbin.		Marlinton.		Marlinton spring.	Ronceverte, Greenbrier River.	Alderson, 80-foot well.	Hinton, Greenbrier River.
	84-foot well.	Greenbrier River.	Greenbrier River.	Knapp Creek.				
Turbidity	0	0	0	0	0	0	0	0
Color	22	40	35	35	40	40	5	45
Iron (Fe)	.5	0	0	2	2	(a)	(b)	(a)
Calcium (Ca)	40	0	....	34	0	31	151	40
Total hardness (as $CaCO_3$)	66	14	28	35	11	37	....	49
Alkalinity	58	11	30	24	8	34	183	39
Sulphates (SO_3)	0	0	0	0	0	0	45	0
Chlorides (Cl)	9	5	9	9	9	9	22	14

[a] Very slight trace. [b] Slight trace.

NEW RIVER FROM GREENBRIER RIVER TO GAULEY RIVER.

Hinton, W. Va.—Hinton (population 4,500) is an important town commercially and a railroad division headquarters. Sanitary conditions are unfortunate here. The water

supply of the town is pumped raw from Greenbrier River, about a mile above Hinton. In view of the above-described conditions in that stream the quality of this supply needs no comment.

At the junction of Greenbrier and New rivers there is in the stream a sharply marked dividing line between the clear Greenbrier water and the muddy brown current of New River. The drainage area of New River yields to that stream a great deal of silt and clay, besides ore washings from mines, so that a summer shower will make its water very turbid for several days, yet will not appreciably cloud the Greenbrier. Field assay shows that the water of New River is of fair quality except for this feature. Sedimentation in properly constructed basins would make it very good for industrial purposes. The accumulated pollution of Greenbrier and Bluestone rivers should bar it from use as a source of domestic supply, yet it is so used at some places.

Between Hinton and Thurmond, on New River, there is no town of more than about 1,000 population. The hamlets are massed along the river bank, house after house having its privy located on the river, so that no one would be inclined to drink the raw water at Thurmond (population 450) after inspecting the contamination. It is nevertheless pumped for domestic purposes, though not for drinking by guests, at the large hotel at that town below the mouth of Thurmond Creek.

Field assays show the turbidity of Thurmond Creek, a rapid mountain stream draining a coal region, to be somewhat less than that of the main stream and its quality to be fair in other respects. It is polluted by drainage from a cluster of houses about 100 feet above the mouth.

Pl. V, *A* gives some idea of the rapidity of the current of New River at this point and makes unnecessary the discussion of its profile. It is evident that a stream so rapid will show very little self-purification, so that pollution entering at any point will be carried downstream practically unchanged, except, perhaps, as to the coarser matters, for many miles below. The domestic use of this water raw at Thurmond is very dangerous.

Field assays of water from New River and Thurmond Creek.

[Parts per million.]

Determination.	New River at Hinton.	Thurmond Creek at Thurmond.	New River at Thurmond.
Turbidity	700	90	148
Color	35	17	61
Iron (Fe)	0	(a)	(a)
Calcium (Ca)	46	28	40
Total hardness (as $CaCO_3$)	63	49	59
Alkalinity	54	22	53
Sulphates (SO_3)	[b] 10	33	[b] 5
Chlorides (Cl)	....	9	9

[a] Very slight trace. [b] Estimated.

Below Thurmond the banks of the river are thickly dotted on both sides with little hamlets inhabited by coal miners. The Chesapeake and Ohio Railroad runs along the west bank and the Kanawha and Michigan Railroad along the east bank. At every station privies overhang the banks, sometimes half a dozen within a few feet. Although the total population as far down as Montgomery is not over a few thousand, it is unfortunately true that nearly all its excrement discharges into the stream.

GAULEY RIVER.

What has been said of New River is also true of Gauley River, a beautiful stream entering New River at Gauley Bridge, a village of a few hundred population. At Camden, near

the source of the Gauley, the water is very clear and as pure as any found in a state of nature so far as dissolved mineral solids are concerned. With proper sanitation along its course the stream would be an asset of great value in the wealth of the State. The privy of the railroad station at Camden on the Gauley is located on the bank of the stream, so that excreta may seep from it into the water at all times and ordinary rains may wash much pollution into the stream. As the population of this section is very small the sum total of the pollution as far down as Gauley Bridge is not great. The field assay at Gauley Bridge shows that the Gauley at this point is still a very pure and clear stream, its waters being sharply defined against the yellow current of New River. A sample of Cherry River, the principal branch of Gauley, taken at Richwood, shows water of the same character, although somewhat highly colored. Much lumbering is carried on in this section and there is some pollution of the stream by the floating population of the lumber camps, so that at Richwood the water of Cherry River is not used for drinking. This follows the rule observed in other sections—that the small towns at the head of a polluted stream are the first to abandon its use as a water supply. The water supply of Richwood is derived from drilled wells that range in depth from 200 to 300 feet. The water is of very good quality for a water drawn from this depth. It is fairly soft and should be quite satisfactory for general use, although it is by no means equal to the water of Cherry or Gauley rivers if they are kept clean.

Richwood is the principal town drained by the Gauley. There are a number of small communities besides, but it is probable that the total population of the area drained is not over 3,000. It would require only the most ordinary care to keep this stream pure and undefiled.

Field assays of waters of Gauley River basin.

[Parts per million.]

Determination.	Camden, Gauley River.	Richwood.		
		Gauley River.	Cherry River.	Public supply.
Turbidity	0	0	0	0
Color	40	44	70	17
Iron (Fe)	1	5	Trace.	1
Calcium (Ca)	0	0	0	40
Total hardness (as $CaCO_3$)	7	21	14	90
Alkalinity	11	17	15	85
Sulphates (SO_3)	0	0	0	0
Chlorides (Cl)	9	9	9	19

There are very few springs in this section and most of these fail during the latter part of the summer. The spring at Fayette, which comes out of the rock beside the railroad track, a hundred yards or so below the railroad station, is much used for drinking. Its water is very soft, but the high chlorides are disquieting. The spring at Kanawha Falls is much larger and is piped down from the rock for the use of the village, which has a population of about 100. It is a typical soft water.

KANAWHA RIVER FROM GAULEY BRIDGE TO ELK RIVER.

Below Gauley Bridge, New River becomes the Kanawha and is lined on both banks with coal-mining hamlets, all contributing privy droppings to the stream.

The field assay of Kanawha River at Gauley shows a poor water in comparison with that of the Gauley or of Cherry River. The stream was fairly clear at the time of the assay—a rare condition. The channel is very rocky and rough, the river in many places flowing over bare ledges of rock. Although many coal mines discharge into the stream with more or less regularity, the traces of iron and sulphates are so slight as to show that so far as the disinfecting influence of mine drainage is concerned the consumers of this water have no protection.

Montgomery, W. Va.—In spite of pollution the raw water is used as a public supply at Montgomery. At this place the belief is entertained, as at other places in the Monongahela basin, that the mine drainage entering the river exercises sufficient germicidal influence in the water to make it safe for drinking. The field assays of water from New and Kanawha rivers fail to disclose a single instance where there was free acid in the water or where the sulphate and iron contents indicated the presence of mine drainage to more than a slight degree. Inspection of both shores of the river from its source down to the mouth at Point Pleasant reveals no considerable outfall of mine drainage. While there are a large number of mines, there seems to be very little acid water coming out of them, certainly not enough to be of any sanitary importance.

The quality of ground water obtainable at this point is shown by the field assay of water from the 145-foot well at Montgomery. It is too hard to be very satisfactory for domestic uses and its slight cloudiness casts some doubt on the safety of the well from contamination.

Field assays of waters from upper Kanawha basin.

[Parts per million.]

Determination.	Kanawha at Gauley.	Spring at Fayette.	Spring at Kanawha Falls.	145-foot well at Montgomery.	Kanawha River at Montgomery.
Turbidity	0	0	0	0	0
Color	70	17	45	62	70
Iron (Fe)	.5	(a)	(a)	9	1
Calcium (Ca)	96	(a)	0	100	40
Total hardness (as $CaCO_3$)	59	45	31	139+	45
Alkilinity	44	[b] 4	26	133	55
Sulphates (SO_3)	[b] 5	0	0	[b] 5	[b] 5
Chlorides (Cl)	9	20	7	65	9

[a] Slight trace. [b] Estimated.

ELK RIVER.

Sutton and Clay, W. Va.—Elk River is used raw for public supply at Sutton (population, 1,200), about 40 miles below its source at Webster Springs. Previous to the use of the stream water as a public supply at Sutton (assay on p. 99) there was much typhoid fever, traceable to the use of contaminated wells. The local physicians claim that there has been a great falling off in the number of typhoid-fever cases since the introduction of the river water. Sutton drains into the stream, and below it a number of small hamlets contribute their pollution, especially in the neighborhood of Clay (population, 1,000), the county seat of Clay County. A large mining population drains into the stream from this town down to Charleston, so that the raw water can not be considered safe for domestic use at any point below Sutton.

KANAWHA RIVER AT AND BELOW CHARLESTON, W. VA.

Charleston, W. Va.—The largest town in the southern half of the State is Charleston (population, 15,000), which has gained amazingly in wealth and population within the last few years. It is in advance of other places in this section in recognizing the fact that the water of Kanawha River is unfit for use. Its public supply is drawn from Elk River, a stream of great natural beauty, similar to Cherry River and Gauley River.

The intake of the Charleston waterworks is about a mile and a half above the mouth of Elk River; at this point the current of both Kanawha and Elk rivers is very sluggish, forming a stagnant pool, polluted by the city sewage outfalls. The water company is planning

to move the intake upstream, so as to guard against this pollution being backed up to the intake by wind. The company is also considering the installation of a crib in the bed of Elk River. The present plant is excellent so far as it goes, there being eight modern filter units in use. This plant, however, is sufficient to purify only about one-third of the daily consumption, so that the present procedure consists of filtering one-third of the supply and then mixing the pure water with the polluted water from Elk River. The installation of a crib for Charleston water supply would be of no value whatever, as it would only clarify the water and would not purify it from organic contamination. In view of the large investment already made in mechanical filters at this point, it would seem best to buy a sufficient number of additional filters and provide for their economical operation, insuring a safe water supply from one of the purest streams in the State so far as mineral contents are concerned. Public opinion will probably compel some such plan in the near future.

The quality of ground water obtainable at Charleston is not very good for domestic uses. Field assays (below) of the two deep wells here show that the water of one is fairly soft for water drawn from so great a depth. It is, however, extremely high in iron, which leaves a heavy yellow deposit on the tanks through which it passes. The other well is so high in chlorides that it would probably give trouble in boilers. Both waters are allowed to pour out of pipes into wooden tanks so arranged as to allow free oxidation. The water is then used in the manufacture of ice.

St. Albans, W. Va.—St. Albans (population, 1,200), about 15 miles below, is located at the point where Coal River enters the main stream. The field assay of Coal River (below) shows it to be of good quality except for high turbidity and color, both due to the nature of the drainage area, which is mostly a heavy red soil in a forest country, rapidly being denuded. There is no public supply at St. Albans. The 70-foot well assayed is typical and shows a rather hard water for domestic purposes. From this point the river flows through a rolling farming country, with scattering hamlets along the banks, the largest town being Winfield (population, 500). The stream is not used for public supply below Montgomery.

Field assays of water, Kanawha basin.

[Parts per million.]

Determination.	Charleston.				St. Albans.		Sutton.
	125-foot well.	200-foot well.	Kanawha River.	Elk River.	70-foot well.	Coal River.	Elk River.
Turbidity	0	0	97	0	0	315	0
Color	78	17	90	70	22	140	96
Iron (Fe)	28	16	1	0	(a)	0	2
Calcium (Ca)	41	81	46	....	49	0	....
Total hardness (as $CaCO_3$)	....	....	49	31	118	21	28
Alkalinity	82	103	44	27	52	20	27
Sulphates (SO_3)	0	(b)	[c] 5	0	0	0	9
Chlorides (Cl)	55	280	11	14	39	14	9

[a] Minute trace. [b] Slight trace. [c] Estimated.

OHIO RIVER FROM KANAWHA RIVER TO BIG SANDY RIVER.

GUYANDOT AND MUD RIVERS.

Below the confluence of the Ohio and the Kanawha there are no important towns above Huntington, where two small streams enter, both muddy and sluggish. Guyandot River drains a rather flat valley in southwestern West Virginia, and there are no large towns on its drainage area. It is much used to raft lumber down to Ohio River and is much polluted The field assay (p. 100) of the stream at its mouth at Guyandot (population, 1,800) shows very high turbidity; otherwise the water is of fair quality for industrial purposes. Mud

River, a tributary of the Guyandot, joining it at Barboursville, drains a well-populated section along the line of the Chesapeake and Ohio Railroad. The largest town on this stream is Milton (population, 100). At this point a somewhat interesting experiment was made by the railroad in the attempt to get boiler water free from high turbidity. A pool, 8 by 8 feet and 18 feet deep, was dug about 100 yards from the river bank, the water seeping through the bank from the stream into the pool. This water was pumped to a tank for locomotive use, but has been for sometime abandoned. Comparison of field assays show that the water gained about 50 per cent in hardness by its filtration through the ground and lost only about one-third of its turbidity, the particles of soil probably being too fine to be caught by the filtration. Both Mud River and the Guyandot would be suitable for industrial use if properly sedimented with coagulant so as to remove the suspended matter.

OHIO RIVER AT HUNTINGTON, W. VA.

The water supply of Huntington (population, 12,000) is drawn from Ohio River, filtered. As the river receives the drainage of Kanawha and Guyandot rivers in West Virginia and Raccoon Creek, Guyandot Creek, and Symes Creek, Ohio, near Huntington, the water must be purified to a high degree to be safe for drinking. For this reason the completeness of the equipment of the Huntington waterworks should be a matter of local pride and general congratulation. Huntington has the best filtration plant in West Virginia—perhaps the only one employing a bacteriologist. It is controlled by the American Waterworks and Guarantee Company, which employs Doctor Witherell to make serial analyses here as at Newcastle and Butler, Pa. The plant pumps from Ohio River by means of five large mains, separately controlled by gate valves and opening at varying distances from the shore so that the disturbance of the water resulting from variations in the height of the river can, to some extent, be counteracted by pumping from different levels. The sedimentation basins are very large and discharge the clarified water into six modern steel filter tanks designed by the company, differing slightly from the Jewell type in the form of cleaning apparatus and in minor details. The pure water is caught in a large tank below the filters and pumped into the mains. The plant is kept in fine condition within and without and is in every way a credit to the town.

The field assay shows the effluent from the mechanical filters to be of very good quality, the mineral content being not appreciably higher than that of the raw water at Pittsburg. The incrusting solids are not high enough to cause trouble in boilers. A fair quality of ground water is obtained in this section, the field assay below being of water from a 57-foot well at the machine shop. The wells in this section range from 50 to 70 feet deep, the one given being typical.

Field assays of water from Milton, Guyandot, and Huntington, W. Va.

[Parts per million.]

Determination.	Milton.		Guyandot.	Huntington.	
	8 by 8 foot well.	Mud River.	Guyandot River.	57-foot well.	Ohio River, filtered.
Turbidity	180	300	667	0	0
Color	80	35	45	22	....
Iron (Fe)	0	0	(a)	1.25	(b)
Calcium (Ca)	107	....	Some.	179	61
Total hardness (as $CaCO_3$)	118	76	55	....	76
Alkalinity	96	48	13	159	30
Sulphates (SO_3)	....	....	0	[c] 20	[c] 20
Chlorides (Cl)	39	....	10	29	11

[a] Very slight trace. [b] Slight trace. [c] Estimated.

TWELVEPOLE CREEK.

Twelvepole Creek, which enters the Ohio at Kenova, drains a long, narrow valley containing a scattering farming population.

Dunlow, W. Va.—Dunlow, near the head of the stream, is a small village without either public water-supply or sewerage. The well assayed (below) is at the railroad station and is disused. The high color of the water is due to débris thrown into the well. Evidently a fair quality of water could be obtained here. The spring water is much softer but is liable to high turbidity after excessive rain, as at the time the assay was made. The supply is too small to be of value except for private uses. The field assay of the creek (below) shows excellent water except for the high suspended matter. The hardness is very low, probably being mostly magnesium carbonate. For any industrial purposes this water could be made available by plain sedimentation. It is somewhat used for drinking purposes in the raw state and evidences of privy contamination are plentiful.

Wayne, W. Va.—The stream follows the course of the railroad and receives dejecta from outhouses at every station, so that at Wayne (population 400) the most considerable town on its drainage area, it is altogether unfit for use. There is a deplorable scarcity of water at Wayne, the well assayed (a dug well) being the only important source of supply. Although this water is of good quality so far as mineral matter is concerned, the well is liable to surface contamination, being partly supplied from the roofs of the court-house, which are guttered to lead into it. There are no drilled or bored wells in the town. In summer all the ground water fails, when water is drawn from Twelvepole Creek and used raw. Conditions here are very bad.

Field assays of water from Dunlow and Wayne, W. Va.

[Parts per million.]

Determination.	Dunlow. Twelvepole Creek.	Dunlow. Spring.	Dunlow. 66-foot well.	Wayne. 60-foot well.
Turbidity	350	250	0	0
Color	35	35	+200	17
Iron (Fe)	0	Trace.	12	.75
Calcium (Ca)			36	Trace.
Total hardness (as $CaCO_3$)	28	48		42
Alkalinity	26	36	75	23
Sulphates (SO_3)		0	0	[a] 5
Chlorides (Cl)	9	9	4	9

[a] Estimated.

BIG SANDY RIVER BASIN.

TUG FORK OF BIG SANDY RIVER.

Tug Fork of the Big Sandy, which forms part of the boundary line between West Virginia and Kentucky, probably carries more offensive pollution than any stream in West Virginia, which is saying a great deal. It has its rise near the Virginia line and flows through a densely populated coal region, its tributaries and its own banks being lined at every possible opportunity with privies and other sources of pollution.

North Fork, W. Va.—North Fork, a typical coal camp of this section, has a public supply from a 90-foot well, said to be carefully cased (see assay on p. 103). The only safe water in this section is that drawn from such sources. The Norfolk and Western Railway has put down wells at approximately this depth all along its line. A few of these are not in use, but the majority of them furnish fair water. The field assay shows this well water to be some-

what hard, the high sulphates making it undesirable for use in steam making. Tug Fork is incredibly polluted in its course through this town. A large negro population lives in squalid huts along its banks and discharges excreta continually into its waters, the privies being thickly clustered together in places. The stream is very small at this point, running probably not more than a few second-feet in dry times, so that the state of affairs can be readily imagined.

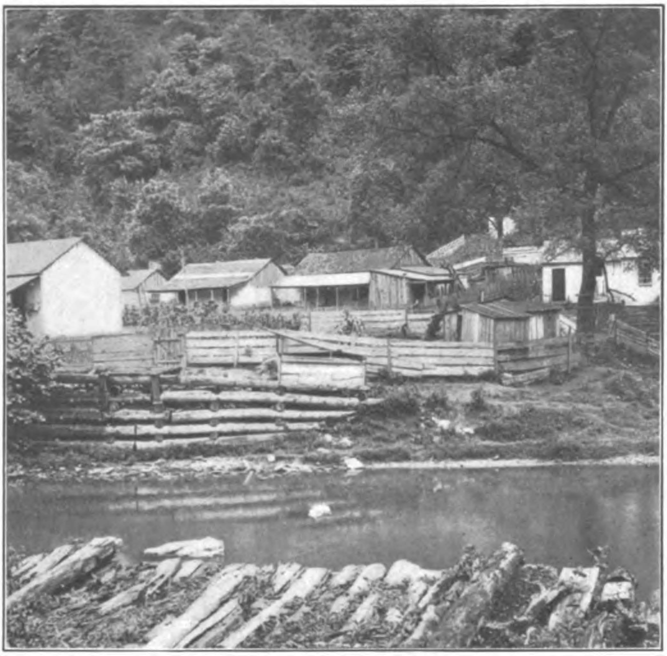
Welch, W. Va.—At Welch (population 600), the largest town at the head of the creek, the extent of the pollution going into the stream is probably greater, but the public supply is rather carefully guarded. It is derived from 200-foot wells, which are pumped to reservoirs. The field assay (p. 103) shows this to be very hard water, undesirable for any purpose except drinking. The assay of the Norfolk and Western well at this point is interesting for comparison with that at North Fork, which shows a somewhat better water. The chief impurities are calcium carbonate and chloride. For industrial uses the water of Tug Fork is far better than either.

Panther, W. Va.—A characteristic case of water-supply pollution in this State may be seen at Panther, a small lumber hamlet (population 100) situated at the confluence of Panther Creek with Tug Fork. Pl. VI gives two views showing the character of the pollution at this point. The upper picture shows a number of houses located on the creek about a mile above its mouth.

It is evident that drainage from these privies and from the houses must continually find its way into the creek. About 100 feet above the mouth of this creek is the intake pipe by which its water is pumped into a large tank for supplying the mill and the town. The mill-dam crosses Tug Fork at a point a short distance below the mouth of Panther Creek. The lower picture shows the greater part of the mill, with a large privy close to the boiler house and another across Panther Creek on the left bank of the Tug Fork. It is evident that heavy rains may at any time cause a sufficient rise in Tug Fork to carry contamination from either or both these privies into the intake pipe on the creek. This supply is filthy. Typhoid-fever statistics are unobtainable, but a practicing physician in this neighborhood informed the writer that he had more cases of typhoid fever than of anything else.

The field assay (p. 103) shows the water of Panther Creek to be very excellent as to inorganic content.

Williamson, W. Va.—Between Panther and Williamson, a distance of about 35 miles, numerous thriving little hamlets scattered along the river, each having a population of a few hundred, add a large amount of privy pollution to its water. Notwithstanding this state of affairs, which is well known to all who travel on the Norfolk and Western Railroad, the raw water is used as a source of public supply at Williamson (population 1,800). A number of the citizens realize the danger of using this polluted water and efforts are being made to raise enough money to provide a pure supply. It has been planned to build a filter well in the bed of Tug Fork for this purpose. This would free the supply from the high turbidity which is at present one of its drawbacks and would make the tap water clear and inviting, but would not assure safety to the consumers from water-borne disease. No really satisfactory supply can be gotten for Williamson by this means. Either a complete ground-water system should be installed or steps should be taken to provide a mechanical filter. The quality of the ground water obtainable here is shown by the field assay of the Norfolk and Western Railroad well at the station. Although somewhat hard it is good water, quite satisfactory for general use, and if the well were properly cased would be free from danger of pollution.



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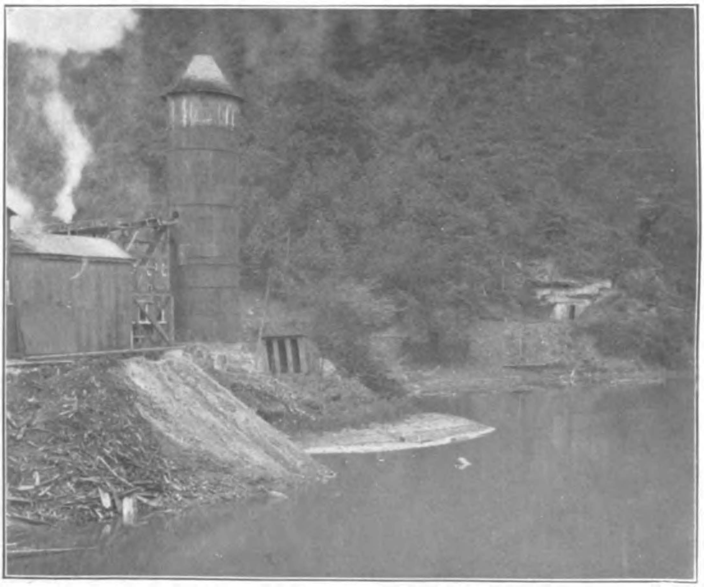

B

TUG FORK OF BIG SANDY RIVER, NEAR PANTHER, W. VA., PUBLIC-SUPPLY INTAKE.

A, One-half mile above intake; *B*, 50 feet below intake.

Field assays of water from basin of Big Sandy River.

[Parts per million.]

Determination.	North-fork, W. Va.	Welch, W. Va.		Panther.	Williamson, W. Va.	
	90-foot well.	Well.	200-foot well.	Panther Creek.	93-foot well.	Tug Fork.
Turbidity	0	0	0	0	0	0
Color	22	10	34	78	70	44
Iron (Fe)	2.5	1	1.25	1	4	0
Calcium (Ca)	96	56	110	0	96	27
Total hardness (as $CaCO_3$)		132		21		62
Alkalinity	77	58	43	32	120	28
Sulphates (SO_3)	106	[a] 5	115	0	[a] 5	[a] 20
Chlorides (Cl)	20	62		7	9	14

[a] Estimated.

BIG SANDY RIVER BELOW TUG FORK.

Kenova, W. Va.—Kenova (population 1,000), a few miles below Huntington, formerly took its water from driven wells. The supply is now drawn from Big Sandy River without purification. The field assays show this to be a much better water for any purpose than that of the Ohio River, the extremely high turbidity of the Ohio putting it out of the question for industrial uses before filtration.

Field assays of water from Big Sandy and Ohio rivers at Kenova, W. Va.

[Parts per million.]

Determination.	Big Sandy River.	Ohio River.
Turbidity	0	422
Color	70	44
Iron (Fe)	0	0
Calcium (Ca)	51	50
Total hardness (as $CaCO_3$)	49	69
Alkalinity	78	52
Sulphates (SO_3)	[a] 10	[a] 10
Chlorides (Cl)	19	24

[a] Estimated.

SUMMARY OF CONDITIONS BELOW PITTSBURG.

The water-supply problems before municipalities on Ohio River and on the Kanawha are not fundamentally different from those confronting towns on Allegheny and Monongahela rivers. In the case of the Ohio we have seen that although the water is heavily contaminated by sewage from over half a million people, it is extensively used for drinking in its raw state. The only possible plea for such use is that there is self-purification going on in the river. No elaborate argument is needed to show the fallacy of this plea after the discussion already presented. It is sufficient here to say that conditions on the Ohio are less favorable to purification by detention than on the Monongahela, where purification has been shown to be imperfect or inefficient. For this inefficiency there are two reasons: First, although the Ohio is well canalized, its greater slope and greater quantity of water make its velocity considerably higher than that of the Monongahela; second,

enormous freshets, which occur in the Monongahela in the spring, happen much more frequently in the Ohio, every heavy rain causing a sharp rise, and as the difference between high and low water in this river is 50 feet or more, it is perfectly clear that pathogenic material deposited at the bottom by sedimentation could be scoured out at frequent intervals, poisoning the water for use as a source of public supply. The only way to obtain pure water from the Ohio is to resort to filtration, and the experience of numerous towns in the valley and on the Mississippi River has shown that for this turbid water mechanical filtration is more practicable than slow sand filtration. This is partly because of the ability of small towns to purchase and operate a small filter plant, the cost of the English system being prohibitive, and partly because waters of such high turbidity clog sand filters very rapidly, causing a greatly increased operating expense.

In spite of these conditions, on the whole stretch of stream between Pittsburg, Pa., and Catlettsburg, Ky., there is but one town—Huntington, with about 12,000 inhabitants—efficiently operating a filtration plant, and but three towns where natural filtration of any importance has been attempted—Moundsville and Point Pleasant, in West Virginia, and Gallipolis, in Ohio. The typhoid fever statistics obtainable for Gallipolis condemn all three supplies, and it is altogether likely that a heavy percentage of unreported cases should be added to the official figures. Altogether there is urgent need in this section for education along sanitary lines.

The tributary streams seem worse than the Ohio, because they are so much smaller and the contamination is so much more apparent. The cases noted where privies are located but a few hundred feet or a few miles above the intake of a public supply are not cited as unusual or extreme cases. On the contrary, in describing these conditions, an effort has been made to speak as moderately as possible. The facts themselves are sufficiently startling. It is a practically universal custom in West Virginia to build privies on running streams if it is possible to do so without going too far from the house. This was found to be the case to a greater or less degree on every stream, of whatever size, in the State. As a result every stream in West Virginia is grossly polluted and at the same time used without purification for domestic water supply.

On New and Kanawha rivers the conditions are even worse than on the Ohio, on account of the closely collected coal-mining population along the banks of the streams. The velocity of the water in these streams is so high that detention is a negligible factor although the Kanawha is to some extent canalized, and the only influence toward self-purification that need be considered is the germicidal effect of mine drainage and ore washings. It has been shown above that neither sulphuric acid nor the sulphates are present in this water in sufficient quantity to make them at all comparable with the waters of the Monongahela and Youghiogheny. It has been shown such influences are ineffective in purifying the Youghiogheny. On Kanawha and New rivers they are practically negligible, being just sufficient to impart unpleasant qualities to the water without having any germicidal effects.

ERIE, PA.

The city of Erie (population, 60,000) is located on the south shore of Lake Erie and of Presque Isle Bay, a small body of water about 4 miles long and 1½ miles wide, with an average depth of 15 feet, although a portion of the bay is 22 feet deep. The bay is landlocked save at the eastern end, where a 300-foot channel connects it with Lake Erie.

The first city supply was derived by gravity from a spring-fed reservoir. On the abandonment of this system, many years ago, the supply was drawn from the bay at a point 975 feet north of the southern shore. As the city grew in population and the sewers of many thousands of people poured their daily pollution into the bay, the supply speedily became unfit for use, and in 1896 the present intake was built. It is 60 inches in diameter and extends for 8,000 feet out into the bay.

The present supply is therefore taken from what is practically a large sedimentation basin of the dimensions above given, the detention in which, though somewhat disturbed by the

wind and the rising and falling of the lake level, would yet cause great improvement in the quality of the water if the pollution were not of the grossest character. The fact is, however, that the contamination is so offensive in kind and so great in amount as to make the water utterly unfit for drinking or domestic use in its raw state. The conditions were very well summarized by Judge Walling in his recent decision of the suit brought by certain persons to restrain the commissioners of the city of Erie from proceeding with the improvement of the supply.

The city is situated on land descending to the bay, into which the contents of 62 miles of sewers are emptied, and which also receives the washings from 31 miles of paved streets and much filth from barns and other buildings. Nearly 10,000 water-closets are in daily use in the city, the discharge from which is carried into the bay. A large amount of garbage and offal is also thrown into the bay from ships in the harbor and from fish houses and other buildings on the shores. The creeks that run through the city into the bay are practically open sewers from the county farms and other places west of the city. The city of Erie is thus using the bay both as a cesspool and as a source of water supply. With the sewage from all these sources daily going into the bay, there to be circulated by the movements of the water till the whole is simply somewhat diluted sewage, and the city at the same time pumping its water out of the pollution, the figures showing typhoid mortality seem surprisingly low. The following table, taken from statistics by the board of health of the city of Erie, given in its annual report for 1904, shows the number of deaths in this city from typhoid fever as well as the rate per 100,000 of inhabitants, from 1876 to 1904, inclusive:

Typhoid mortality at Erie, Pa.

Year.	Deaths.	Rate per 100,000.	Year.	Deaths.	Rate per 100,000.
1876	13	20	1891	30	71
1877	10	40	1892	24	55
1878	6	23	1893	15	34
1879	7	22	1894	17	37
1880	4	14	1895	21	45
1881	17	58	1896	18	37
1882	19	62	1897	13	26
1883	6	19	1898	8	16
1884	6	18	1899	18	35
1885	10	29	1900	18	34
1886	11	31	1901	8	15
1887	7	19	1902	13	25
1888	9	23	1903	17	29
1889	19	48	1904	27	46
1890	29	71			

That the figures show no uniformity of increase during the earlier years is probably due in part to incomplete returns and in part to the more accurate methods of diagnosis of the present day, which distinguish as typhoid fever some diseases that were formerly classified otherwise. For the years 1887 to 1895 the tendency is seen to be quite clearly upward. The extension of the intake pipe in 1896 had its effect in lowering the mortality rate for a time, as is shown by the steady decrease for three years, 1896 to 1898, inclusive. That this improvement could continue long with the rapid growth of population and coincident increase in pollution was not to be expected. With the exception of the year 1901 the figures have climbed steadily upward until in 1904 there were in the city 46 deaths from typhoid fever to the hundred thousand—certainly too many.

The dangerous character of this water should be obvious to anyone who sees the sewage going into the bay and then sees it pumped out as drinking water. Sanitary inspection is to-day considered more trustworthy, in the absence of conditions allowing perfect control,

than sanitary analysis. In this instance there are no factors modifying the character of the supply that can not be accurately estimated, as the water is not subject to great fluctuations in quality or quantity. The evidence at hand may therefore be well supplemented by sanitary analyses of this water made by Dr. W. P. Mason, covering the period from 1892 to 1901, which show the gradual increase in sewage pollution by the steady rise of the chlorine content. As the quantities considered in water analysis are very small, a change of a small fraction of a part per million may be significant, in the absence of adequate cause for it. No sanitary analysis of water is valuable except when it is considered in conjunction with the exact conditions. In this case the conditions exclude any factor but the increase in sewage pollution to account for the increase of chlorine.

Sanitary analyses of water at Erie, Pa.

[Analyses by W. P. Mason, in parts per million.]

Sample No.	Place and date.	Total solids.	Albuminoid ammonia.	Free ammonia.	Nitrates.	Chlorine.
1	Intake June, 1892	132	0.175	0.100	Trace.	6
2	Pittsburg dock, June, 1892	128	.200	.130	Trace.	6
3	Big Bend, June, 1892	138	.145	.065	Trace.	7
4	Faucet in residence, June, 1892	141	.190	.050	Trace.	6
5	New intake, June, 1900	115	.146	.155	0.137	2
6	New intake, September, 1900	105	.133	.073	.063	9.5
7	New intake, November, 1900	171	.048	.081	.087	8.0
8	New intake, February, 1901	135	.112	.080	.200	8.5

Aside from the remarkably low figure for June, 1900, the rise in the chlorine content of this water is too steady and too uniform to be mistaken. The low figure mentioned may have been due to the fact that the sample was taken just before the seasonal change in the water strata, due about August at Erie. The summer's accumulation of sewage was probably stirred up from the bottom, making the chlorine content in the next sample higher and the figure for the June sample very low. This, however, would only partially explain the difference. The final figures, 8.5 parts per million, acquire further significance when compared with those of December, 1889, when at the inlet of the water works, then much closer to the shore, the chlorine content as determined by Doctor Cresson was but 3.188 parts per million.

The columns headed free ammonia, albuminoid ammonia, and nitrates give the quantity of nitrogen in this water expressed in the three forms in which it was determined. So expressed, the amount of nitrogen found in water is an index, under proper conditions, of the amount of organic matter present. Taken by itself, any one of these factors is meaningless; taken in conjunction with a number of others in cases where it is impossible to control the factors of impurity, as in the Mississippi River, they may be misleading; but in the case of Presque Isle Bay there is no possibility that much organic matter gets into the water except through sewage contamination. This being admitted, the figures show that there was much organic pollution at the time of the analyses.

Nor is bacteriological evidence wanting of the contamination of the basin. The following figures, summarizing analyses made by Doctor Mason from April, 1901, to February, 1903, shows the presence of bacteria which are invariably associated with wastes from animal intestines:

Bacteriological analyses of water at new intake, Erie, Pa.

Date.	Taste.	Odor.	Color.	Turbidity.	Alkalinity.	Bacteria per c. c.	Bacillus coli communis.
Apr. 1, 1901	0	0	0.1	6	47.5	5,500	Present.
June 10, 1901	0	0	0	0	50	....	Present.
Oct. 1, 1901	0	0	Trace.	Slight.	50	119	None.
Jan. 22, 1902	0	0	.22	(a)	50	637	Present.
Apr., 1902	0	0	.2	Slight.	90	402	Present.
Feb. 20, 1903	0	0	10	....	....	....	

[a] Very slight.

All but one of these samples contained bacillus coli, which could only have entered the water by fœcal contamination. The evidence seems conclusive that Presque Isle Bay is, as was said by Mr. George Y. Wisner in his report to the commissioners upon the advisibility of getting a new supply, "little less than a diluted cesspool."

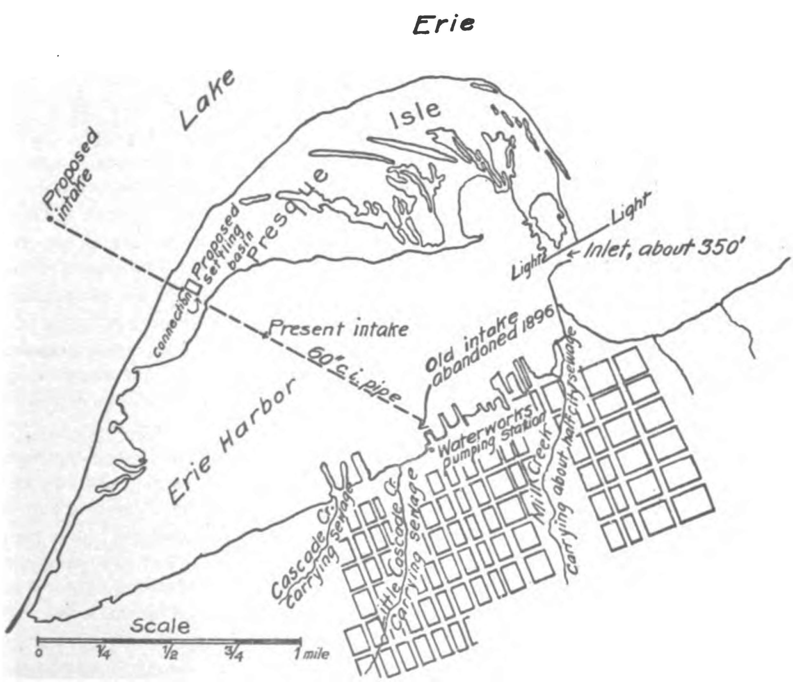

FIG. 3.—Map of Erie, Pa., and Erie Harbor, showing proposed improvement in water supply.

It became necessary either to filter this water or to get a new supply from Lake Erie. The former course would involve a very large first cost, both for the filtering plant itself and for the intercepting sewer that would be necessary to convey all contamination out into the lake, as otherwise the imperfections of practical operation would make the effluent highly suspicious. The most economical solution of the problem, as well as the best in the long run, is certainly the plan adopted—that of extending the present intake pipe out into Lake Erie to a sufficient distance to insure a pure supply for some time to come.

The following analyses of Lake Erie water show that it is greatly superior to the water of the bay, and that it contains no bacteria that point to sewage contamination:[a]

Analyses of Lake Erie water.

[Parts per million.]

Date.	Color.	Turbidity.	Free ammonia.	Alb. ammonia.	Chlorine.	Nitrates.	Alkalinity.	Total solid.	Bacteria.
Apr. 1, 1901	0.1	12	0.039	0.075	6.5	0.15	42.5	140	3,000
June 10, 1901	0	0	.02	.095	6	.075	50	126	....
Oct. 10, 1901	0	Slight.	.071	.093	6	.037	50	134	70
Jan. 22, 1902	.1	Slight.	.053	.109	7	.125	55	172	126
Apr. 19, 1902	.025	....	.056	.159	8	.025	100	142	80
Feb. 20, 1903	5	25	.039	.105	5	.1	97.5	147	2,490

Although this water is far superior to the present supply, the increase in alkalinity, probably due to sewage contamination, would seem to indicate that in time filtration will be necessary. The direction of the prevailing winds on the lake, together with the eastward current, causes the sewage from Toledo, Sandusky, Cleveland, and Ashtabula to be drifted eastward. The great distance of Toledo and Sandusky from Erie make it probable that their sewage is completely oxidized before it reaches the Erie intake. Ashtabula, a city of 13,000 population, lies about 48 miles west of Erie, and Cleveland, with 381,000 people, about 90 miles west. The currents set along the south shore and such sewage from these places as does not sink to the bottom within the first few miles after leaving the towns is swept eastward, steadily decreasing in quantity and becoming less dangerous in quality until near Presque Isle it begins to take a more northeasterly direction. Yet at no time can it probably dangerously affect the quality of the new supply, as there seems to be every favorable condition in this immense body of water to insure perfect oxidation of the contaminating influents before the Erie intake is reached. The contingency of increasing pollution of the lake water is of less present importance than the turbidity occurring at certain seasons of the year, which, as may be seen from the foregoing analyses, may be high enough to give the water an objectionable appearance. This difficulty can certainly be overcome by the construction of sedimentation basins on Presque Isle, as provided in the plans.

The projected improvements, designed by Mr. George H. Fenkell, and now going rapidly forward under his direction, contemplate the extension of the 60-inch steel intake pipe about 10,000 feet northward beyond the present intake, across Presque Isle Peninsula and into Lake Erie, with 5-foot gate valves for connections with the settling basins, etc., and a timber crib, weighted with stone, protecting the end of the intake pipe, which terminates in a special opening about 25 feet below mean lake level. The work shows a number of construction features of interest, in particular the submarine joint designed for this work. This has a gasket of lead pipe snugly fitting the steel intake pipe, and when the joint is made the 16-inch bolts are screwed up so as to bring the flanges together, compressing the lead between them and insuring a tight joint.

[a] Rept. Dept. Health, 1902 and 1904.

INDEX.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 161.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports; (2) Monographs; (3) Professional Papers; (4) Bulletins; (5) Mineral Resources; (6) Water-Supply and Irrigation Papers; (7) Topographic Atlas of United States—folios and separate sheets thereof; (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

Most of the above publications may be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are delivered to Senators and Representatives in Congress, for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they may be had at practically cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they may be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the thirteenth in Series L, the complete list of which follows (PP=Professional Paper, B=Bulletin, WS=Water-Supply Paper):

SERIES L, QUALITY OF WATER.

WS 3. Sewage irrigation, by G. W. Rafter. 1897. 100 pp., 4 pls. (Out of stock.)

WS 22. Sewage irrigation, Pt. II, by G. W. Rafter. 1899. 100 pp., 7 pls. (Out of stock.)

WS 72. Sewage pollution near New York City, by M. O. Leighton. 1902. 75 pp., 8 pls.

WS 76. Flow of rivers near New York City, by H. A. Pressey. 1903. 108 pp., 13 pls.

WS 79. Normal and polluted waters in northeastern United States, by M. O. Leighton. 1903. 192 pp., 15 pls.

WS 103. Review of the laws forbidding pollution of inland waters in the United States, by E. B. Goodell. 1904. 120 pp.

WS 108. Quality of water in the Susquehanna River drainage basin, by M. O. Leighton, with an introductory chapter on physiographic features, by G. B. Hollister. 1904. 76 pp., 4 pls.

WS 113. Strawboard and oil wastes, by R. L. Sacket and Isaiah Bowman. 1905. 52 pp., 4 pls.

WS 121. Preliminary report on the pollution of Lake Champlain, by M. O. Leighton. 1905. 119 pp., 13 pls.

WS 144. The normal distribution of chlorine in the natural waters of New York and New England, by D. D. Jackson. 1905. 31 pp., 5 pls.

WS 151. Field assay of water, by M. O. Leighton. 1905. 77 pp., 4 pls.

WS 152. A review of the laws forbidding pollution of inland waters in the United States, second edition, by E. B. Goodell. 1905. 149 pp.

WS 161. Quality of water in upper Ohio River basin and at Erie, Pa., by S. J. Lewis. 1906. — pp., 6 pls.

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WASHINGTON, D. C.

SEPTEMBER, 1906.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

DESTRUCTIVE FLOODS IN THE UNITED STATES IN 1905

WITH A

DISCUSSION OF FLOOD DISCHARGE AND FREQUENCY

AND AN

INDEX TO FLOOD LITERATURE

BY

EDWARD CHARLES MURPHY
AND OTHERS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1906

CONTENTS.

ILLUSTRATIONS.

DESTRUCTIVE FLOODS IN THE UNITED STATES IN 1905.

By E. C. Murphy and others.

INTRODUCTION.

There were few very destructive floods in 1905. The most remarkable flood or series of floods of the year were those in the Gila River basin in Arizona. From January 15 to April 30 occurred a series of seven floods—almost a continuous flood—remarkable for the total volume of flow. In November there was in this basin another flood, which was remarkable for its magnitude, being the largest on record on Salt River. The other large floods of the year occurred on comparatively small streams. Few lives were lost and the damage was small compared with that of some previous years.

In addition to the credits for data given in the body of this paper the writer desires to acknowledge his indebtedness to F. H. Newell, chief hydrographer, for valuable suggestions; and to James Dun, chief engineer Santa Fe Railway System, who has furnished data and transportation over the Santa Fe lines to flooded sections.

FLOOD ON PEQUONNOCK RIVER, CONNECTICUT.

By T. W. Norcross.

INTRODUCTION.

A flood on this stream on July 29 and 30, popularly known as the Bridgeport flood, destroyed a quarter of a million dollars' worth of property. It was due primarily to a very heavy local rainstorm, during which 11.32 inches of rain fell in seventeen hours at Bridgeport, Conn., where it was heaviest. The flood wave was enlarged by the failure of four dams in the watershed.

The Pequonnock is a small stream that rises in the northeastern part of Fairfield County, Conn., flows south about 14 miles, and empties into Long Island Sound at Bridgeport. Its fall from source to mouth is 460 feet. Its channel is rather narrow, with numerous bends, and its banks are low and flat. Its drainage basin is mainly hilly pasture land, with little timber, and has an area of 25 square miles.

PRECIPITATION.

The following table, prepared from records of the United States Weather Bureau at Bridgeport, shows the precipitation during this storm:

Table showing rate of rainfall at Bridgeport, Conn., July 29-30, 1905.

Time of beginning.	Time of end.	Time elapsed.	Precipitation.	Average rate per hour.
		h. m.		
July 29—11.40 a. m.	1.30 p. m.	1. 50	0. 10	0. 06
1.30 p. m.	4.15 p. m.	2. 45	5. 90	2. 15
4.15 p. m.	7.50 p. m.	3. 35	4. 18	1. 17
7.50 p. m.	12.00	4. 10	0. 77	0. 18
July 30—3.00 a. m.	5.20 a. m.	2. 20	0. 37	0. 16
July 29—11.40 a. m.	12.00 p. m.	12. 20	10. 95	0. 89
July 29-30—11.40 a. m.	5.20 a. m.	17. 40	11. 32	0. 64

The following table gives the precipitation at several neighboring rainfall stations from July 23 to 31, inclusive:

Precipitation at stations near Bridgeport, Conn., July 23–31, 1905.

Station.	July—								
	23.	24.	25.	26.	27.	28.	29.	30.	31.
Cream Hill [a]	0.07	0.53	....	Tr.	....	....	0.86	2.39	0.23
Hartford	0.02	0.83	Tr.	....	....	....	0.04	0.72	Tr.
Hawleyville	0.05	0.77	....	....	....	....	0.16	2.22	0.35
New Haven	0.43	0.37	....	Tr.	....	....	0.90	0.41	0.01
Norwalk	0.26	1.03	....	....	....	....	1.43	0.31	0.09
Torrington	0.02	Tr.	1.16	....	....	Tr.	....	0.97	0.40
Waterbury	0.06	0.83	....	Tr.	....	....	1.77	....	0.04
Beaver Dam [b]	0.31	0.39	....	....	....	....	9.86	0.61	......
Bridgeport	0.39	0.63	....	....	....	....	10.95	0.55	......
Easton	....	0.62	....	....	....	....	7.91	0.18	......
Bunnell Pond	0.36	0.48	....	....	....	....	[c] 8.00	[c] 2.00	......

[a] The first six stations are United States Weather Bureau stations. Data furnished by William Jennings, United States Weather Bureau observer.
[b] The last four stations are stations of the Bridgeport Hydraulic Company. Data furnished by S. P. Senior, superintendent Bridgeport Hydraulic Company.
[c] Approximate.

The table shows that the storm was very intense over a comparatively small area, the greatest rainfall occurring in the Pequonnock Valley in the vicinity of Bridgeport.

DISCHARGE.

The run-off from a rainfall of 8 to 11 inches in seventeen hours on this quick-spilling basin soon overtaxed the natural capacity of this rather small, crooked channel and overflow occurred, carrying débris that more or less reduced the channel capacity, especially the spillways of dams. Four dams failed, each one increasing the magnitude of the flood wave and adding débris to the already choked spillway of the dams below.

The rate of flow at Bunnell's dam, about 1½ miles above Bridgeport, at the time of its failure was computed to be 3,930 second-feet, or 157 second-feet per square mile. The length of the spillway was 52 feet, and the depth of water on the crest at the time of failure was 7.48 feet. Two smaller waste openings discharged 105 second-feet each.

This is a comparatively small run-off from such a large rainfall, and it is very likely that the maximum rate of flow occurred after the dam failed. By computing the run-off from rainfall and using a run-off factor of 0.5, the maximum rate of flow at this dam is found to be 248 second-feet per square mile. If 0.6 is used as the run-off factor the maximum rate is 297 second-feet per square mile.

DAMAGE DONE.

The Toucey dam, on a brook entering the Pequonnock from the west near Long Hill, gave way shortly before midnight of the 29th. It was 100 feet long, 10 feet high, built of rubble masonry laid in cement. Ward's milldam at Trumbull, on the Pequonnock, failed when the flood wave from Toucey dam struck it. It was 60 feet long, gave a head of 15 feet, and was built of rubble masonry laid in cement mortar. It was founded on a ledge and probably failed by sliding. At about 1 a. m. July 30, the dam at Bunnell Pond, 1½ miles above Bridgeport, failed. It was 800 feet long, 28 feet high, built of earth with a masonry spillway. It had a puddle core, a top width of 30 feet, upper slope 1.5 to 1, lower slope 1 to 1. In addition to a spillway 52 feet long, there were two openings 3 feet 10½ inches by 1 foot 8½ inches and a circular opening 4 feet in diameter. Failure resulted from overflow, due in part to the blocking of spillway by débris. The fourth dam to fail was the Berkshire milldam. This was a masonry tidewater dam 140 feet long and 7 feet high. Its failure was probably due to undermining.

Several bridges were damaged, traffic was impeded, and ships at the mouth of the river were damaged. Fortunately the tide was at ebb stage when the flood wave reached the mouth of the river, otherwise the damage to shipping would have been greater.

FLOOD ON SIXMILE CREEK AND CAYUGA INLET, NEW YORK.

INTRODUCTION.

On June 21, 1905, occurred the largest and most destructive flood on Sixmile Creek and Cayuga Inlet in the recollection of the oldest inhabitant of Ithaca, N.Y. Up to that time

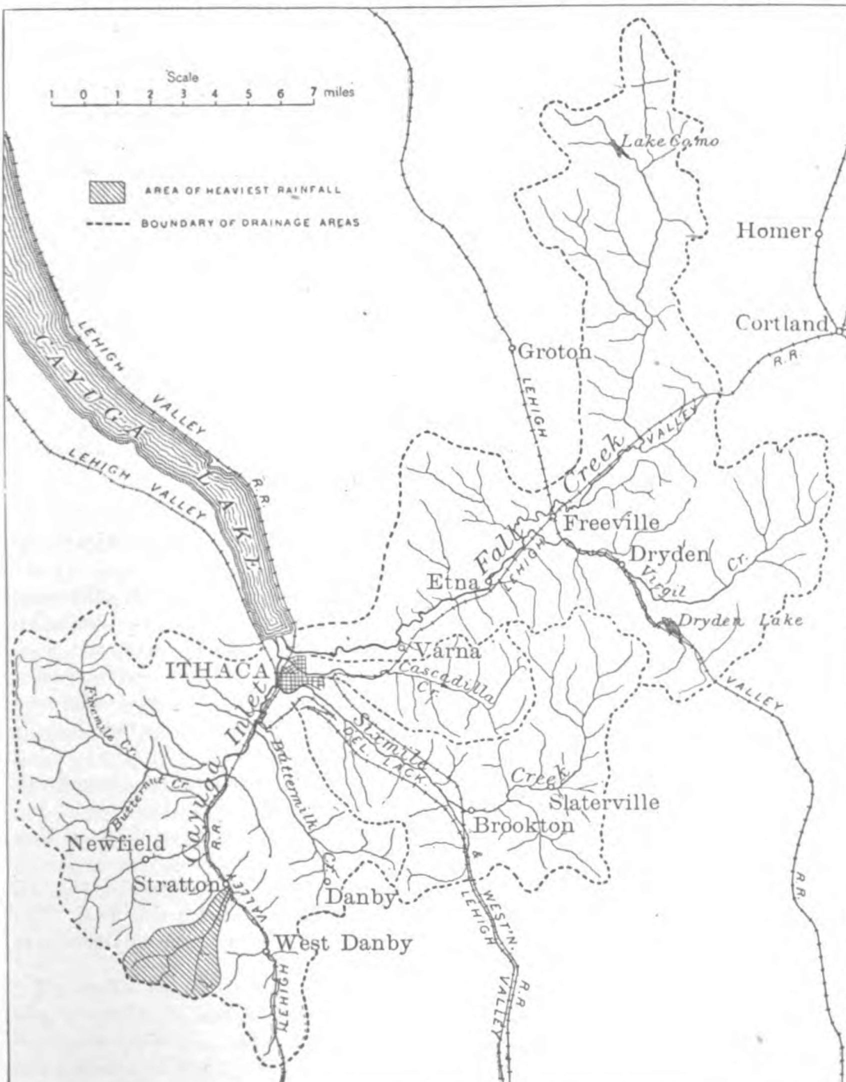

Fig. 1.—Drainage basin of Sixmile Creek and Cayuga Inlet, New York.

the flood of 1857 had been regarded as the largest on this stream, but the depth of overflow during the flood of June 21, 1905, was at least 1 foot greater than during the flood of 1857, as shown by well authenticated flood marks. The flood of 1905 was due to a cloud-burst,

which fortunately did not cover a very large area. Had a storm of the intensity of this one covered the whole drainage area of these two streams the damage done at Ithaca and vicinity would have been very large.

The city of Ithaca is so situated that the effect of a storm in the drainage basin is almost the greatest possible. It is located on a low, flat area, with steep hills on three sides. The drainage area is characterized by steep slopes and nearly impervious soil, and is shaped somewhat like a fan, so that the three principal streams unite at about the same place in the city. Thus a very large volume of water, compared with the size of the drainage basin, is brought into the city very rapidly. The banks are eroded where the velocity of the water is high, the protection is poor, and gravel and small bowlders are deposited in a short time in other places where the velocity is low.

Fall Creek, Cayuga Inlet, Sixmile Creek, and Cascadilla Creek drain the area at the southern end of Cayuga Lake. Sixmile and Cascadilla creeks are really tributaries of Cayuga Inlet near its mouth (see fig. 1). Fall Creek, the largest of these four, drains an area of about 117 square miles. In about 22 miles it falls from an elevation of 1,306 feet at Lake Como to 381 feet at its mouth. The upper half of this basin is hilly, cultivated land; the lower half is more broken, with steep, pastured slopes. Cayuga Inlet drains an area of about 93 square miles, southwest of Ithaca. The watershed is rough, with steep pastured slopes, and some of the smaller tributaries extend to an elevation of about 1,900 feet above the sea level. Sixmile Creek drains an area of about 46 square miles lying directly east of Cayuga Inlet. Cascadilla Creek drains an area of about 16 square miles lying east of Sixmile Creek basin. Both of these basins have extremely steep slopes and their beds fall very rapidly until they reach the city limits.

Floods of considerable magnitude frequently occur on these streams. They are usually due to large rainfall over only a portion of one or another of the watersheds, and consequently all of the streams are not in destructive flood at the same time.

PREVIOUS FLOODS.

Flood of June 17, 1857 (a).—The flood of 1857 was due to a heavy rainfall over a comparatively small area, mainly on the watershed of Sixmile Creek. Almost no damage was done on Fall Creek and comparatively little on Cayuga Inlet.

There were two dams on Sixmile Creek at this time and both were destroyed. The fallen timbers of these structures formed a temporary dam in front of the stone arch bridge on Aurora street, and this obstruction caused the water to overflow its banks and run down State street and other streets parallel to it, flooding a part of the city which was not flooded during the flood of 1905. This stone arch bridge and other bridges on Sixmile Creek were destroyed by the flood. Marks left by this flood near State street show that at this place the flood of 1905 was about 14 inches higher than that of 1857.

Flood of December 14 and 15, 1901.—The flood of 1901, which is one of the three large floods that have occurred on Sixmile Creek, took place on the night of December 14 and the morning of December 15, as the result of heavy rain over a considerable portion of central New York and northern Pennsylvania. The United States Weather Bureau gage at Ithaca recorded 3.09 inches of rain from 8 a. m. on December 14 to 8 a. m. on December 15. All the streams entering the southern end of Cayuga Lake were in destructive flood. The maximum rate of flow of Sixmile Creek at Van Netta dam, about 2 miles above Ithaca, was computed by Prof. C. L. Crandall to be 6,070 second-feet.

FLOOD OF JUNE 21, 1905.

GENERAL FEATURES.

Copious rains had fallen for two or three days previous to the flood of June 21, 1905, and on the 21st heavy thunderstorms passed over the south-central part of the State, accompanied

a Data taken mainly from Ithaca Journal of January 24, 1857.

by very heavy local rain. The rainfall at six places in or near the drainage basins of Sixmile and Cascadilla creeks from 8 a. m. on the 20th to 8 a. m. on the 21st was as follows: Ithaca, 1.82; Elmira, 1.05; Binghamton, 1.00; Cortland, 1.38; Waverly, 0.53; Perry City, 1.26, and Kings Ferry, 1.73. The hourly rainfall at Ithaca from 4 a. m. to 4 p. m. on the 21st varied from 0.03 inch to 0.58 inch. These figures show only the local character of the storm. The rainfall indicated by them would not cause even a small flood on these streams. The intensity of the storm can be judged only by the maximum rate of flow and the damage done on each of the streams. This damage indicates that an exceedingly heavy rain fell on two comparatively small areas—on Sixmile Creek, in the vicinity of Brookton and Slaterville, and on Cayuga Inlet, in the vicinity of Stratton (see fig. 1).

FLOOD ON SIXMILE CREEK.

The heaviest rainfall occurred in the upper part of the watershed in the vicinity of Slaterville and Brookton. Several bridges here were destroyed and the banks of the streams were badly eroded. In some places a new channel was formed and the old channels were closed with bowlders and gravel. Some of the bottom land along the creek was badly damaged by the deposit of gravel upon it.

The maximum rate of flow is computed from measurements of cross section and slope between Aurora Street Bridge and Tioga Street Bridge. The channel here is approximately rectangular. From these data and a value of the coefficient of roughness "n" of 0.030, it is found that the mean velocity equals 15.8, and that the maximum rate of discharge was 8,980 second-feet, or 195.2 second-feet per square mile of drainage area.

The maximum rate of flow was also computed at the Sixmile Creek dam, 4 miles upstream from Ithaca, from the head on the dam, length of crest, and length of abutments. The discharge at this place was found to be 8,500 second-feet, which agrees closely with the computed flow after taking into account the difference of drainage area at the two places.

FLOOD ON CAYUGA INLET.

The flood on this creek began at about 10 a. m. and lasted for about five hours. Mr. G. H. Ellison, county commissioner, who lives on this stream and who has been over the greater part of the flooded area, states that the storm covered an area approximately circular in shape, the radius of the circle being about 3 miles. The storm was central over the small stream southwest of Stratton. Judged from the erosion of its channel the flood in this creek was exceedingly large. The highway and railroad bridges near the mouth of this stream were located at a bend in the stream, the width between abutments of the bridges being about 25 feet. A new channel, between 80 and 90 feet wide and 3 feet deep, was cut around these bridges, the old channel being filled with bowlders and gravel. The area of the watershed of this tributary is about 2.6 square miles. The extent of the erosion indicates that the rainfall on this basin must have been very great. The main stream also cut a channel around the bridge near the mouth of this gulch. The highway bridge, located about a half mile below the mouth of the gulch, was washed away, and the right bank of the stream was eroded for a distance of 50 feet back from the abutment.

AREA OVERFLOWED.

The stream began to overflow State street, Ithaca, about 3 p. m., reached its maximum stage about 5 p. m., and subsided below the street level about 1 a. m. of June 22. This overflow extended from a point about 1,200 feet east of the creek to a point 1,100 feet west of it, had a maximum depth of 3 feet, and a cross-section area of 4,120 square feet. The high-water line at this bridge was 8.9 feet above lake level on August 1, and about 9.5 feet above lake level just prior to the flood. The boundary of the area overflowed during this flood is

shown on fig. 2. This area is probably somewhat less than that overflowed during the flood of 1901, for Fall Creek was not in flood and there was little overflow from Cascadilla Creek. But in some sections of the city the overflow reached places it had never reached before—at least not in thirty years.

DAMAGE.

The Lehigh Valley Railroad, which runs along Cayuga Inlet for several miles, was damaged to such an extent that trains could not pass over this part of the line for about a week. The first estimate of the damage done by this flood along this railroad between Ithaca and Sayre was $65,000. A later estimate, however, placed it at $100,000. The estimated cost of replacing bridges, protecting them from floods, and repairing the damage to roads in the town of Newfield was $8,000.

The dam at the Van Netta mill was swept away by the flood, leaving the city pumping station on Sixmile Creek without water for the city's supply, and without water power to work some of the pumps. The highway bridge over this dam was also destroyed.

The new 30-foot dam about 4 miles above Ithaca, on this stream, was uninjured; but the dam a few hundred feet below it, forming a water cushion for the water flowing over the 30-foot dam, was destroyed. The pipe line extending from the dam down the creek was considerably damaged by the washing out of the concrete supports.

The bridge at Clinton street was washed away; also the right abutment and the bank for a distance of about 55 feet back from the abutment (see fig. 3). The flood of 1901 eroded, to a large extent, the right bank of this stream from this bridge up to a point about 300 feet above the electric railway car barn. After the flood this bank was protected along a part of this distance by a concrete wall, along another part by piling and planks, and along a third part by piling and concrete. The concrete part was not injured by the flood of 1905 along the portion protected by piling, but the piles were washed away or badly damaged, and the part protected by piles and concrete was damaged to some extent. The water found its way back of the piling and eroded the bank in some places back to a distance of 55 feet. Fig. 3 shows a cross section of the channel at Clinton Street Bridge, taken August 1, 1905. The shaded area was washed away by the flood. The old channel is now filled with gravel to a depth of 2 to 3 feet.

Meadow Street Bridge was carried 900 feet downstream and left with a large mass of lumber in front of the Lehigh Valley Railway bridge. About a month after the flood this bridge was taken apart and replaced in its former location.

State Street Bridge was damaged to some extent and was closed to heavy traffic for about a month. A mass of drift collected in front of the bridge and prevented the water from passing freely through the natural channel.

SUGGESTED MEANS OF PREVENTING OR LESSENING OVERFLOW.

Overflow of the lowland in the vicinity of Ithaca results from two causes—(1) backwater from the lake, (2) overflow of one or more of the four creeks before mentioned. The elevation of the normal level of Cayuga Lake is 381 feet above sea. Its surface elevation fluctuates from about 5 feet above normal to 1½ feet below normal.

A considerable area of land at the south end of the lake stands less than 5 feet above normal lake level, and is consequently subject to overflow from the lake, but it is not within the scope of this investigation to consider overflow from the lake alone. The elevation of the lake surface does, however, in a measure, affect the overflow of the creeks, because it controls the surface slope near the mouth of each. The sidewalk on State Street Bridge is about 9 feet above normal lake level, or 4 feet above high-water lake level. There would, therefore, be a surface slope of from 2 to 3 feet from the under surface of State Street Bridge to the lake, a distance of about 1 mile, when the lake level is at its maximum height.

The effects of floods on Sixmile Creek and Cayuga Inlet are intensified by the smallness of the channel and the obstructions in the streamway from State Street Bridge to a point below Buffalo Street Bridge. The average width of the channel along this portion of it is only 67

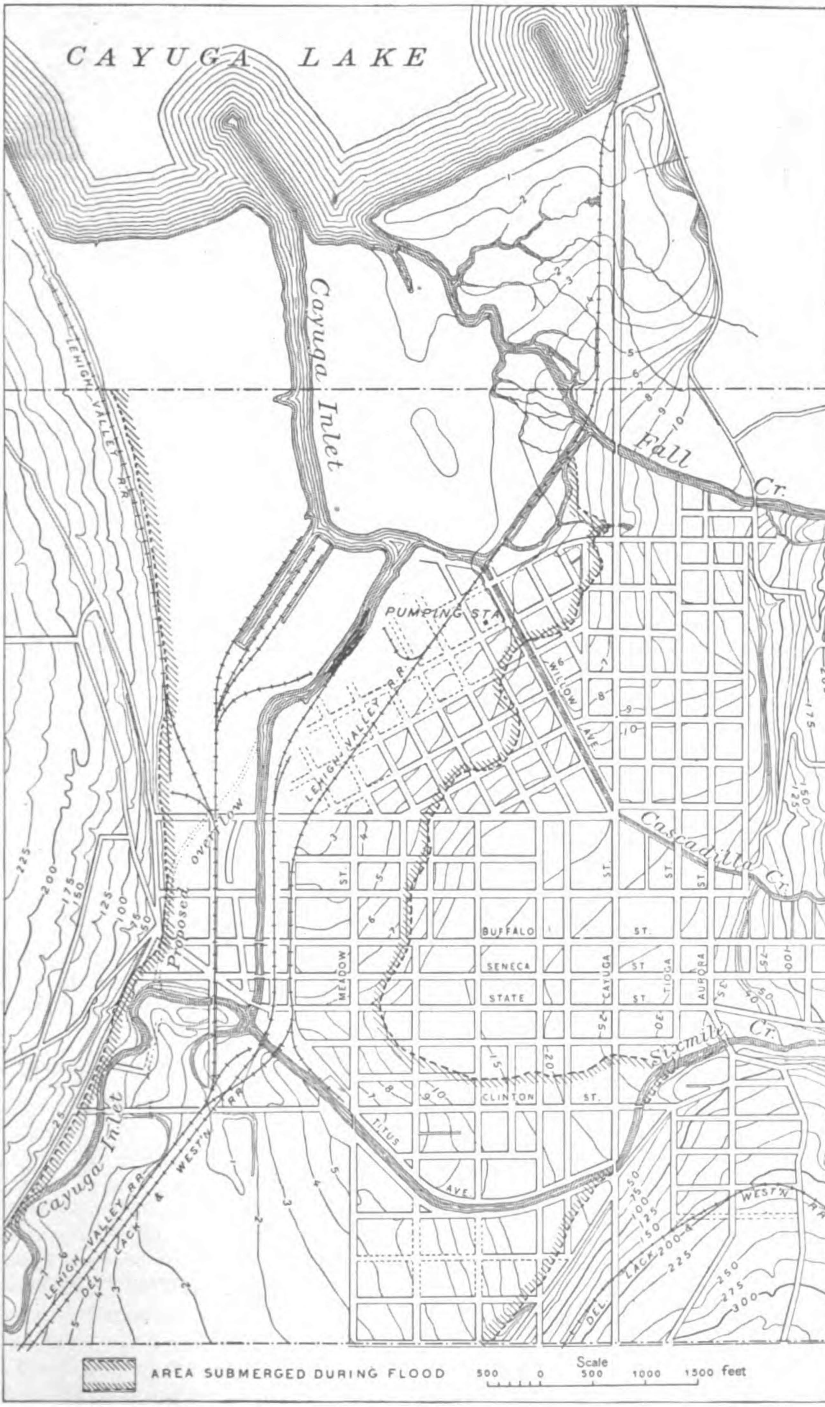

FIG. 2.—Map showing area overflowed, location of bridges, etc., Ithaca, N. Y.

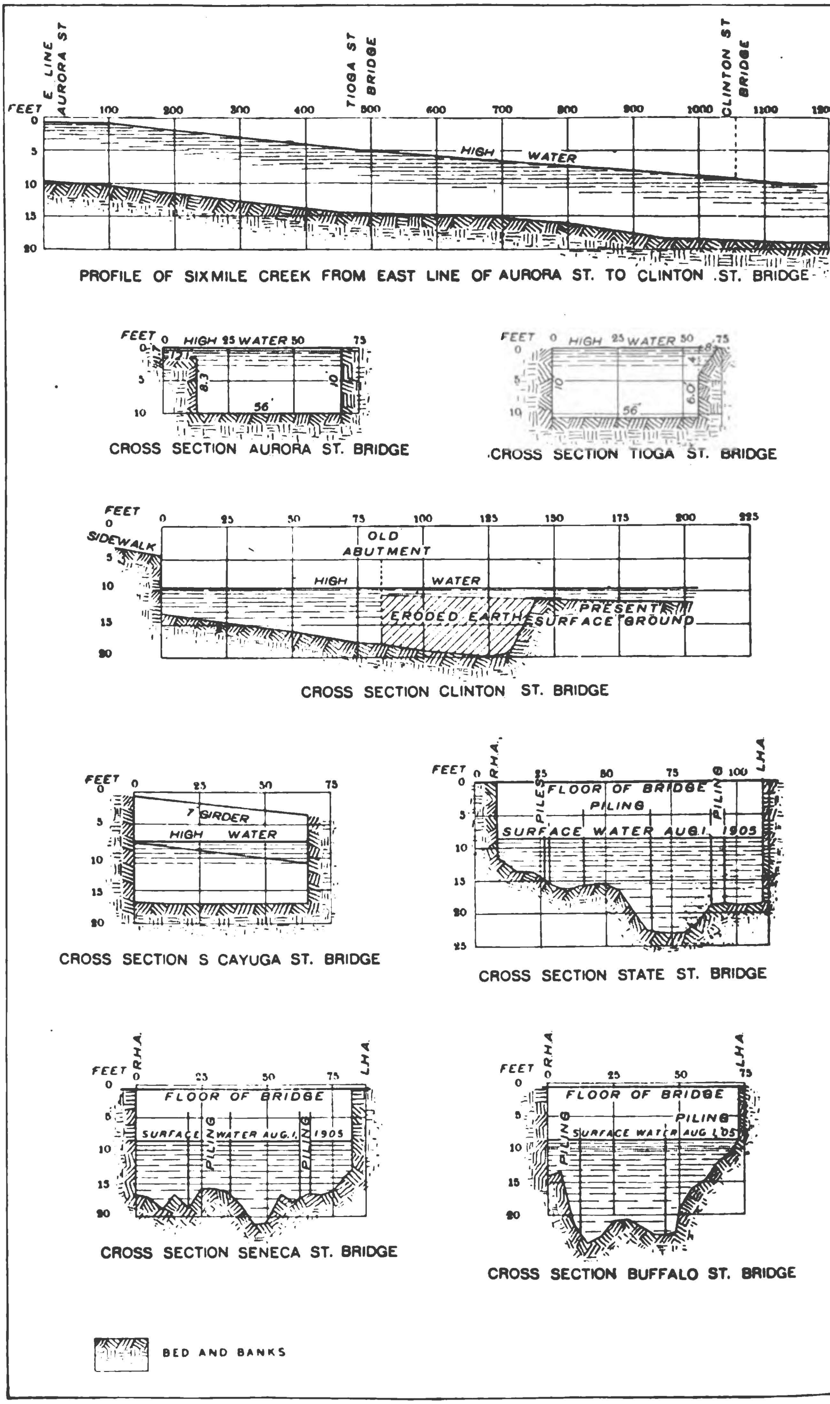

FIG. 3.– Flood profile and cross sections of Sixmile Creek.

feet. There are two or three groups of piles under each of these bridges, one being the group that supports the draw span of the bridge. The water cross section at each of these bridges up to the bridge floor, not making any allowance for the area of the piles in the channel, is as follows: State Street Bridge, 1,625 square feet; Seneca Street Bridge, 1,244 square feet; Buffalo Street Bridge, 1,210 square feet. These sections and the portion of each obstructed by piles are shown in fig. 3. With a surface slope of 2 to 3 feet, Cayuga Inlet, if unobstructed, would discharge 6,000 second-feet. The maximum flow being more than 15,000 second-feet, there remains a flow of 9,000 second-feet to be provided for, either by storage or by the construction of an overflow channel, if the overflow of State street is to be prevented during a flood of the magnitude of that of June 21, 1905.

It is not within the scope of this investigation to determine whether or not storage sufficient to control this amount of flow is obtainable. Judging, however, from the topography of the watershed, one would readily infer that such storage is possible; but the second solution of the problem, namely, the construction of an additional channel to carry off this surplus water, would be the most feasible. This solution has several times been recommended, but satisfactory data have not heretofore been available to determine the proper size of the channel. This channel would be about a mile long, and would be cut through low ground of little value and easy of excavation.

IMPROVEMENT OF CHANNEL OF SIXMILE CREEK.

The damage done by floods upon this creek, from a point about 800 feet above Aurora Street Bridge to Cayuga Street Bridge, would several times pay the expense of suitable bank protection. The flood of 1905 has taught a useful lesson as to the kind of protection, its height, and the proper width of the channel. The concrete work near Aurora Street Bridge was uninjured by this flood, but was not sufficiently high. The width of channel at this place is about 56 feet and the maximum depth of the water was about 10 feet. The bed was not injured by scour. Below Cayuga Street Bridge the grade of the stream bed decreases; hence the width of the channel should increase as State Street Bridge is approached. The height of the banks and the width of channel can easily be computed from the maximum rate of flow and the slope of the bed.

CONCLUSION.

Rainfall records are of little value in estimating the maximum flow of streams, especially the smaller ones. The maximum rates of flow are due to storms of short duration and great intensity over small areas, and there is seldom a rain gage in the area of greatest precipitation. The maximum rate of flow of Sixmile Creek at Ithaca, June 21, 1905, was about three times greater than its supposed maximum rate computed from rainfall records.

FLOOD ON THE UNADILLA AND CHENANGO RIVERS, NEW YORK.

By R. E. Horton and C. C. Covert.

INTRODUCTION.

Considerable damage was done in the valleys of the Unadilla and Chenango rivers, in Chenango, Otsego, and Madison counties, New York, on September 3 and 4, by a flood that caused the overflow of the smaller streams of these basins and the failure of culverts and reservoirs. The flood was the direct result of a short rain storm, of great intensity, that occurred after several days of rain, which had saturated the soil and filled the streams nearly bank full.

Unadilla River rises in the southern part of Herkimer County, flows southeastward for about 50 miles, and empties into the Susquehanna near Sydney. Its chief tributary is Wharton Creek, which enters it at New Berlin. The watershed is long and narrow, with

numerous side grass-covered valleys and a moderate amount of woodland. The soil is clay and gravel, of considerable depth, underlain by rock. The smaller streams are precipitous, with beds of bowlders, shingle, and gravel, and as their headwaters are approached the beds become solid rock.

FIG. 4.—Map of drainage basins of Unadilla and Chenango rivers, New York.

Chenango River is located just west of the Unadilla, and its basin greatly resembles that of the Unadilla, being long and comparatively narrow, with numerous small side valleys. The side slopes are grass-covered and moderately steep.

The drainage areas of the streams on which most of the damage was done by this flood are approximately as follows:

	Square miles.
Mill Brook above Ackerman dam	9.4
Wharton Brook above mouth	95.0
Unadilla River above South Edmeston	172.0
Unadilla River, South Edmeston to electric light company's dam at New Berlin	32.0
Total, Unadilla River above dam, New Berlin	204.0
Susquehanna River above Sydney	914.0
Mad Brook above storage reservoir, near Sherburne	5.0
Chenango River above South Oxford Branch	423.0

PRECIPITATION.

The following table gives the depth of rainfall, in inches, at several stations of the United States Weather Bureau in the vicinity of these basins from August 29 to September 4, inclusive. Fig. 4 shows the watersheds of these streams and the location of some of these rainfall stations:

Precipitation in vicinity of the Chenango and Unadilla watersheds August 29 to September 4, 1905.

Station.	August—			September—				Total.
	29.	30.	31.	1.	2.	3.	4.	
Bouckville	0.31	2.13	0.00	0	0.22	0.80	1.36	4.82
Cooperstown	0.00	1.50	0.00	0	0.55	1.15	0.22	3.42
Cortland	0.30	1.25	0.28	0	0.11	(a)	1.53	3.47
De Ruyter	0.06	2.61	0.01	0	0.22	1.30	0.17	4.37
New Lisbon	0.31	1.70	0.02	0	0.42	0.12	1.92	4.49
Oneonta	(a)	1.84	0.00	0	Tr.	0.00	0.28	2.12
Oxford	0.15	1.41	0.40	0	0.42	0.50	0.55	3.43
Richmondville	0.00	0.96	0.00	0	0.49	0.03	0.24	1.72
South Kortright	0.18	1.43	0.28	0	Tr.	0.38	0.52	2.79
Little Falls	0.23	0.98	0.00	0	0.58	0.55	2.52	4.86
Graefenberg	0.31	0.33	0.80	.....	....	1.20	0.87	3.51
Savage reservoir	0.38	0.37	0.91	.....	....	1.21	0.87	3.74

[a] Amount included in next measurement.

The Graefenberg and Savage reservoirs are located near Utica, a few miles north of the Chenango-Mohawk divide.

These rainfall data indicate only in a general way the precipitation for this period over these basins. None of the stations are located in the areas where the greatest damage was done. The rainfall at several of the stations was greater on August 30 than during the flood, this fact showing that the precipitation over the flooded basins was probably much greater than shown by these records. The measured rainfall and the damage done indicate a very heavy rain of short duration over a comparatively small area. The effect of this local storm was intensified by the heavy rains of the previous six days.

DISCHARGE.

The maximum discharge of some of the streams in the flooded area is given in the following table:

Maximum discharge of streams in Unadilla and Chenango basins.

Stream.	Locality.	Date.	Area (square miles).	Discharge.	
				Second-feet.	Second-feet per square mile.
Mill Brook	Ackerman dam, near Edmeston.	September 3, 4, 1905.	9.4	2,300.0	241.0
Unadilla River	New Berlin Electric Light and Power Company's dam.	September 3, 4, 1905.	204.0	8,200.0	40.0
Mad Brook	Upper storage reservoir, Sherburne.	September 3, 4, 1905.	5.0	1,300.0	262.0
Starch Factory Creek.	Near Utica	September 3, 4, 1905.	3.4	712.0	209.0
Do	do	June 21, 1905	3.4	647.5	190.4
Do	do	March, 1903	3.4	367.0	108.0
Do	do	October 10, 1903	3.4	313.0	92.0
Do	do	March 25, 1904 [a]		372.0	109.4

[a] Melting snow.

The discharge of Starch Factory Creek at the gaging stations near Utica has been included for purposes of comparison. The records of flow at this station have been kept for three years, and the discharge obtained there is more accurate than that obtained at the other places mentioned in the table.

It is seen that the flood of September, 1905, on Starch Factory Creek was somewhat larger than that of June 21, 1905, and considerably larger than those of 1903 and 1904. As far as known, the storm that caused the flood of June, 1905, did little damage in the Unadilla and Chenango basins. The duration of the September flood of 1905 was from twelve to fifteen hours, and was somewhat longer on the Chenango than on the Unadilla River.

In the Chenango basin the magnitude of the flood, as well as the damage done, was much less than in the Unadilla basin. This difference was due in part to the interception of a part of the flood water for storage in the State reservoirs in the upper Chenango basin. These reservoirs, which are located in the vicinity of Hamilton, had been drawn down during the months preceding the flood to supply the Erie Canal. As a result the run-off from the area tributary to them—comprising 30 square miles, mostly hillside land—was intercepted and stored in the reservoirs, and the damage that would have resulted from the passage of this volume of water down the streams was thus prevented.

The maximum discharge of Chenango River at Binghamton, near its mouth, during this flood was 17,400 second-feet at 5 p. m. September 5. On March 2, 1902, the discharge of this stream at this place was 35,950 second-feet—that is, twice as great as during the flood of 1905. The maximum discharge of the Susquehanna at Binghamton during the flood was 29,240 second-feet at 5 p. m. September 4. On March 2, 1902, the maximum discharge here was 60,400 second-feet—that is, more than twice that measured during the flood of September, 1905. The March flood on the Susquehanna was not only twice as large, but was of much longer duration, and was due to the melting of ice and snow, as well as to rain.

DAMAGE.

The greatest damage caused by this storm occurred in the village of Edmeston, at New Berlin, and elsewhere along Wharton Creek and Unadilla River. The failure of the Sherburne Waterworks reservoir, in the Chenango basin, resulted in severe damage below it.

The railroads passing through these basins suffered heavily and were out of service from one to two weeks. Three dams at Mill Creek above Edmeston failed, also one at Edmeston and one at New Berlin. These failures intensified the flood. The damage in the vicinity of the village of Edmeston is estimated at $25,000. The damage at New Berlin resulted from the choking of a stone arch culvert over a tributary of Paper Mill Brook, three-fourths of a mile above the village. This culvert became clogged with drift and the stream overflowed the arch and washed it away, flowing down Main street, scouring in some places to the depth of 8 or 10 feet, sweeping away the smaller buildings, filling cellars, and causing a loss of $10,000 to residences and business houses in the village. In the township of New Berlin 22 bridges were washed away, ranging in value from $25 to $1,400. The villages of Bridgewater, Brookfield, and North Brookfield also suffered heavily from this flood.

The village of Sherburne gets its water supply from two reservoirs on Mad Brook, about 2 miles northeast of the village. The upper or storage reservoir, having a capacity of 10,000,000 gallons, was formed by an earth embankment 300 feet long, 35 feet high, and 10 feet thick on the top. There is a spillway 35 feet wide, 6 feet deep, with a slope of 1 in 350 at one end. During this flood the water in this reservoir rose to the height of 1 foot above the top of this embankment and scoured out a U-shaped section 150 feet in width at the top to the base of the embankment. The lower reservoir also was damaged to some extent.

Nearly every bridge in the towns of Exeter, Columbus, Sherburne, Pittsfield, Edmeston, and New Berlin were either washed away or badly damaged.

FLOOD ON ALLEGHENY RIVER, PENNSYLVANIA-NEW YORK.

INTRODUCTION.

The spring freshet of March 18-31 on the Allegheny and upper Ohio rivers was not the largest or most destructive that has occurred on these streams, but nevertheless approached closely the maximum recorded stage at some places along the Allegheny and caused much loss of property and inconvenience.

The highest stage at Pittsburg was 29 feet, which is 4.2 feet below the height reached during the great flood of 1884, but only 1 foot below that of the flood of 1904, when about $1,000,000 worth of property was destroyed in western Pennsylvania and eastern Ohio. The highest stage of the Monongahela at Lock No. 4, Pennsylvania, was 27.2 feet, which is 15 feet below maximum recorded stage. The failure of this stream to yield the rate of flow expected resulted in a stage 2 feet less than was predicted.

The flood was the result of rapid melting of snow on five days (March 16-20), and a rainfall of 0.75 inch on the 19th and 0.50 inch on the 20th. The ice gorges held back large volumes of water and augmented the maximum rate of flow.

Allegheny River rises in northern Pennsylvania, at an altitude of about 2,500 feet. It flows northwestward into New York, then southwestward through Pennsylvania, and joins the Monongahela at Pittsburg, Pa., to form the Ohio. Its length, measured along the stream, is 325 miles, and the area drained by it comprises 11,100 square miles. From its mouth to Olean, N. Y., a distance of 255 miles, the slope is gradual and slightly less than 3 feet per mile. From Olean to Salamanca, N. Y., a distance of 23 miles, the fall is 1.85 feet per mile.

The greater part of the watershed is mountainous or hilly, with steep, nearly impervious slopes and no surface storage; hence the run-off is rapid. The rapid melting of snow, which in places in the upper part of the watershed has a depth of 3 feet, and the formation of ice gorges cause great floods, especially in the sluggish stretches of the stream. One of the largest of these ice freshets occurred January, 1877.[a]

[a] Report of Chief of Engineers U. S. Army for 1880, pt. 2, p. 1769.

PRECIPITATION.

There are no authentic records of the depth of snow accumulated during the winter of 1904-5 or its water equivalent. The following record of water equivalent of snow at three places in New York State [a] will show in a general way the probable water equivalent of the snow in the upper part of this basin:

Water equivalent of snow on ground at Hancock and near Utica, N. Y., during February and March, 1905.

Date.	Hancock.	Utica.	Graefenberg reservoir, near Utica.
	Inches.	*Inches.*	*Inches.*
February 6	1.85	2.39	5.06
February 13		3.27	5.97
February 14	2.93		
February 20	3.49		6.25
February 21		3.27	
February 27	2.45		7.30
February 28		3.18	
March 6	2.40	2.89	6.66
March 13	1.30		6.03
March 20	1.35		4.88
March 27			3.37

During the five days comprising March 16-20 the temperature in this basin was as follows:

Temperatures in Allegheny River basin March 16-20, 1905.

Date.	Maximum.	Minimum.	Date.	Maximum.	Minimum.
	°F.	°F.		°F.	°F.
March 16	55	21	March 19	59	42
March 17	62	31	March 20	48	32
March 18	67	36			

These high temperatures were accompanied by considerable rain, especially on March 19 and 20, averaging for 16 stations in this basin 0.75 inch on the 19th and 0.50 inch on the 20th. As a result of this rain and melting snow the tributaries rose rapidly during the 19th and 20th and reached a maximum stage generally on March 20.

[a] Data furnished by R. E. Horton, district hydrographer.

THE FLOOD.

The gage heights at several points are shown in the following table:

Gage heights in feet, in Allegheny River basin, March 18–31, 1905.

Date.	Freeport.[a]	Oil City.[a]	Redhouse, N. Y.[b]	Monongahela River at Lock No. 4, Pa.[a]	Redbank Creek, Brookville, Pa.[a]	Clarion River, Clarion, Pa.[a]	Conemaugh River, Johnstown, Pa.[a]
March 18	10.0	4.2	6.5	9.6	1.4	7.4	6.4
March 19	16.8	15.5	11.4	9.9	5.0	10.8	7.6
March 20	[c] 31.2	17.6	11.6	14.4	5.8	16.0	8.8
March 21	28.5	14.9	11.7	16.5	4.0	11.0	9.0
March 22	26.3	14.1	11.1	27.2	3.8	9.6	7.0
March 23	21.5	12.3	9.9	20.5	2.8	7.7	5.4
March 24	18.0	11.1	9.6	13.3	2.0	6.8	4.5
March 25	17.4	11.0	9.6	12.9			
March 26	16.8	10.8	9.7	13.3			
March 27	17.5	10.4	9.9	13.2			
March 28	18.0	10.3	9.8	12.3			
March 29	15.0	9.4	9.3	10.9			
March 30	13.0	8.6	8.8	10.0			
March 31	11.8	7.9	8.2	9.2			

[a] U. S. Weather Bureau Station.
[b] This gaging station is described in Water-Sup. and Irr. Paper 128, p. 45.
[c] Maximum, 32 feet.

The Freeport station is just below the mouth of Kiskiminitas River and is 28 miles above Pittsburg. The highest stage at Freeport was 32 feet—that is, 31.3 feet above low water—on March 20. The highest recorded stage was 32.7 feet on February 18, 1891. The maximum of 1905 lacked only 0.7 foot of being as high as the highest since 1890 at this place. The following table gives the maximum stage of the river at Freeport each year from 1890 to 1905:

Flood stages of Allegheny River at Freeport, Pa., 1890–1905.

Year.	Date.	Gage height.[a]	Year.	Date.	Gage height.[a]	Year.	Date.	Gage height.[a]
		Feet.			*Feet.*			*Feet.*
1890	January 16	16.0	1895	April 10	20.6	1901	April 21	23.0
1890	April 10	20.0	1896	March 31	20.2	1902	March 1	28.8
1890	May 24	22.1	1897	March 6	19.5	1903	February 5	23.5
1891	February 18	32.7	1898	March 24	25.3	1904	January 23	30.1
1892	March 28	17.5	1899	March 7	17.0	1904	March 4	27.9
1893	May 18	22.8	1900	January 22	17.5	1905	March 20	[b] 31.2
1894	May 22	24.5						

[a] U S Weather Bureau gage heights.
[b] Maximum, 32 feet.

The greatest stage at Oil City, 123 miles above Pittsburg, was 17.6 feet on the 20th. On March 17, 1865, the stage at this place was 21 feet—that is, 3.4 feet higher than during this flood.

The greatest stage at Redhouse, about 15 miles above the New York-Pennsylvania line, was 11.7 feet on March 21. This is less than 9 feet above ordinary low stage. There was no overflow worthy of mention here or above this station.

The maximum stage during this freshet at Lock No. 4, on the Monongahela, about 40 miles above its mouth, was 27.2 feet on the 22d. The rate of flow was 94,000 second-feet. The highest recorded stage is 42 and the highest discharge is 207,000 second-feet. The volume contributed to this flood by this stream was comparatively small. This small run-off is partly due to a freshet of greater magnitude, which occurred from the 8th to the 14th, and which removed most of the snow from the watershed.

The details of river stage at Kittanning, Pa., 45 miles above Pittsburg, are shown below. The ice jam at Ford City, about 3 miles below, broke at about 10.30 a. m. on March 18.

Gage heights and discharge of Allegheny River at Kittanning, Pa., March 18–24, 1905.

Date.	Hour.	Gage height.	Dis- charge.	Date.	Hour.	Gage height.	Dis- charge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
March 18........	10.30 a. m.	16.40	82,900	March 20.........	2.00 p. m.	28.75	240,200
March 18........	11.30 a. m.	15.30	73,000	March 20.........	2.30 p. m.	28.70	239,400
March 18........	3.30 p. m.	12.10	47,830	March 20.........	2.45 p. m.	28.70	239,400
March 18........	4.00 p. m.	11.95	46,810	March 20.........	4.00 p. m.	28.60	237,900
March 18........	4.30 p. m.	11.85	46,140	March 20.........	4.30 p. m.	28.50	236,400
March 19........	11.00 a. m.	16.50	83,840	March 21.........	7.15 a. m.	25.50	192,800
March 19........	12.30 p. m.	17.60	94,560	March 21.........	8.15 a. m.	25.30	190,000
March 19........	2.00 p. m.	18.40	102,800	March 21.........	10.30 a. m.	24.80	182,900
March 19........	2.30 p. m.	18.70	105,900	March 21.........	11.15 a. m.	24.70	181,500
March 19........	3.15 p. m.	19.50	114,700	March 21.........	11.50 a. m.	24.60	180,100
March 19........	4.15 p. m.	20.45	125,600	March 21.........	2.10 p. m.	24.25	175,200
March 19........	4.45 p. m.	20.90	131,000	March 21.........	3.10 p. m.	24.10	173,100
March 19........	5.40 p. m.	22.15	145,640	March 22.........	7.45 a. m.	22.35	149,200
March 19........	5.55 p. m.	22.50	151,200	March 22.........	9.00 a. m.	22.20	147,300
March 19........	6.15 p. m.	22.90	156,600	March 22.........	11.00 a. m.	22.00	144,700
March 19........	6.35 p. m.	23.25	161,300	March 22.........	12.45 p. m.	21.75	141,500
March 20........	7.15 a. m.	28.40	235,000	March 22.........	2.00 p. m.	21.60	139,600
March 20........	8.15 a. m.	28.55	237,200	March 23.........	6.30 a. m.	19.25	111,900
March 20........	11.15 a. m.	28.75	240,200	March 24.........	6.00 a. m.	16.50	83,840
March 20........	12.30 p. m.	28.80	240,900	March 25.........	7.00 a. m.	16.05	76,680

The highest stage at Kittanning was 28.8 feet on the gage, or 26.5 feet above ordinary low water. It lacked 6 to 8 inches of the height reached by the flood of 1865, and probably lacked 8 inches or more of reaching the height of the flood of 1832. The rise was very rapid, about 5 feet the first day and 10 feet the second. The maximum daily rate of discharge was 231,990 second-feet, or 26.7 second-feet per square mile.

FLOOD ON OHIO RIVER.

The gaging station on this stream is at Wheeling, W. Va., 90 miles below Pittsburg, Pa. The drainage above it, including the Allegheny and Monongahela basins, is 23,800 square miles. Beaver River, which joins the Ohio from the north 25 miles below Pittsburg, is the only comparatively large stream entering between Pittsburg and Wheeling. Its drainage area comprises 3,030 square miles. The first comparatively large stream that joins the Ohio below Wheeling is the Muskingum River. It enters from the north at Marietta, 81 miles below Wheeling, and has a drainage of 7,740 square miles.

The magnitude and duration of the flood of March, 1905, can be seen from the data in the following table:

Stages of Ohio River and tributaries during flood of March, 1905.

Date.	Ohio River at Wheeling, W. Va.		Ohio River at Davis Island dam.[a]	Ohio River at Marietta.[b]	Ohio River at Cincinnati.[c]	Beaver River at Elwood Junction, Pa.[d]	Muskingum at Zanesville.[e]	Kanawha at Charleston, W. Va.[f]
	Gage height.	Discharge.	Gage height.	Gage height.	Gage height.	Gage height.	Gage height.	Gage height.
	Feet.	*Sec.-feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
March 18	10.9	54,340	9.5	10.75				
March 19	14.9	85,700	14.1	12.6	25.3	4.3	11.1	6.5
March 20	28.2	205,200	23.2	20.7	22.3	9.6	13.7	7.0
March 21	39.7	329,200	26.1	32.8	21.2	9.0	15.6	8.0
March 22	[g] 42.3	359,600	27.1	39.1	28.8	9.0	17.3	9.8
March 23	41.8	353,700	23.1	40.4	37.1	6.0	16.9	10.8
March 24	34.0	265,600	17.2	38.8	42.2	5.0	15.9	8.5
March 25	26.2	185,500	15.0	33.7	45.0	4.0	14.5	7.3
March 26	23.2	157,000	15.1	27.2	46.8	4.0	13.0	7.2
March 27	22.6	151,500	14.5	23.6	47.0	4.0	11.8	7.0
March 28	21.2	138,900	13.8	21.3	45.4	3.9	10.9	6.4
March 29	19.9	127,500	12.8	19.8	42.2	3.9	10.2	6.0
March 30	17.9	110,400	11.5	18.1	38.7	3.8	9.8	5.5
March 31	15.9	93,790	10.6	16.4	35.2	3.8	9.5	5.3
April 1	14.0	78,500			31.3			
April 2	12.4	65,920			28.4			
April 3	10.9	54,340			26.0			

[a] Highest stage 32.3 feet February 7, 1884.
[b] Highest stage 46.5 feet February 7, 1884.
[c] Highest stage 71.1 feet February 14, 1884.
[d] Highest stage 18 feet May 18, 1893.
[e] Highest stage 35.9 feet March 24, 1898.
[f] Highest stage 46.9 feet September 29, 1861.
[g] Maximum stage 42.7 feet 8 p. m.

The Ohio at Davis Island dam, 5 miles below Pittsburg, reached on March 22 a maximum stage of 27.1 feet, which is 5.2 feet less than the maximum reached during the great flood of February, 1884. On the same date it reached a maximum stage of 42.3 feet and a rate of flow of 359,600 second-feet at Wheeling. On February 7, 1884, the river reached a stage of 53.1 feet at Wheeling and a maximum rate of flow of 494,200 second-feet.

At Cincinnati, Ohio, a maximum stage of 47 feet was reached on the 27th, which is 24.1 feet below the height reached by the flood of 1884. The maximum stage of Beaver River at Elwood Junction, Pa., was 8.4 feet below the highest recorded stage.

During this flood the Muskingum at Zanesville was 18.6 feet below, and the Kanawha at Charleston was 36.1 feet below the maximum recorded stage. It is evident, therefore, that this flood came mainly from the Allegheny River and that its magnitude, compared with other great floods, decreased as it traveled downstream.

The following table gives the date of occurrence and daily rate of flow of the Ohio at Wheeling during the large floods from 1884 to 1905:

Flood flow of Ohio River at Wheeling, W. Va., 1884–1905.

[Danger line, 36 feet; drainage area, 23,800 square miles.]

Year.	Date.	Gage height.	Discharge.	Year.	Date.	Gage height.	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1884	February 5	23.0	155,100	1893	May 19	31.5	239,000
	February 6	38.0	309,800		May 20	29.5	218,400
	February 7	53.1	494,200	1895	January 8	28.8	211,300
	February 8	46.5	410,400		January 9	36.0	287,500
	February 9	41.3	347,800		January 10	30.7	230,700
	February 10	36.0	287,500		January 11	26.0	183,500
	February 11	32.0	244,300	1897	February 23	19.5	124,000
1885	January 17	26.0	183,500		February 24	35.3	279,800
	January 18	32.8	252,800		February 25	37.0	298,600
	January 19	27.8	201,200		February 26	27.0	193,300
1886	April 1	23.8	162,600	1898	March 22	25.6	179,760
	April 2	31.0	233,800		March 23	35.4	280,900
	April 3	28.0	203,200		March 24	[a] 43.9	378,700
	April 6	22.0	146,000		March 25	42.9	366,700
	April 7	31.3	237,000		March 26	37.0	298,600
	April 8	32.0	244,300		March 27	29.9	222,500
	April 9	27.0	193,300	1900	February 10	25.0	173,900
1887	February 8	25.0	173,900	1901	April 20	23.8	162,600
	February 9	30.9	232,800		April 21	37.0	298,600
	February 10	30.6	229,700		April 22	[a] 41.3	347,800
	February 11	29.4	217,400		April 23	37.0	298,600
	February 12	29.8	221,500		April 24	32.2	246,400
	February 13	33.8	263,500		December 17	33.9	254,900
	February 14	29.8	221,500	1902	March 1	28.8	211,300
1888	August 22	16.3	97,060		March 2	42.0	356,000
	August 23	32.2	246,400		March 3	42.0	356,000
	August 24	25.6	179,700		March 4	37.9	308,700
1890	March 23	26.9	192,300		March 5	30.0	223,500
	March 24	32.5	249,600		April 11	32.9	253,800
	March 25	30.4	227,600	1903	March 1	28.6	209,300
	March 26	21.8	144,200		March 2	39.7	329,200
1891	January 3	29.4	217,400		March 3	37.3	308,000
	January 4	32.9	253,800	1904	January 23	34.2	267,800
	January 5	26.8	191,300		January 24	43.9	378,700
	February 17	25.0	173,900		January 25	41.0	344,300
	February 18	40.0	332,700		January 26	31.5	239,000
	February 19	44.6	387,200		March 8	28.4	207,200
	February 20	40.5	338,500		March 9	36.3	290,800
	February 21	34.5	271,000		March 10	29.3	216,400
	February 22	29.8	221,500		March 11	22.3	148,800
1893	February 7	20.9	136,200		April 3	33.9	264,600
	February 8	31.6	240,100	1905	March 11	27.7	200,200
	February 9	32.0	244,300		March 21	39.7	329,200
	February 10	28.0	203,200		March 22	42.3	359,600
	February 11	28.9	212,300		March 23	41.8	353,700
	February 12	32.1	245,400		March 24	34.0	265,600
	February 13	27.0	193,300		March 25	26.2	185,500
	May 18	23.8	162,600				

[a] Probable mean for day. Maximum, 54 feet.

The largest flood at this place during the twenty-two years covered by the table occurred in February, 1884. On February 7 the maximum stage was 54 feet, the mean stage for the day about 53.1 feet, and the rate of flow 494,200 second-feet, or 20.8 feet per square mile. During this flood the river rose 10.8 feet higher, had a rate of flow 134,600 second-feet greater, and was of two days' longer duration than during the freshet of March, 1905. Second in rate of flow was the flood of February, 1891, when the stage at 8 a. m. on the 19th was 44.6 feet, and the greatest daily rate of flow was 387,200 second-feet. Third in magnitude was the flood of March, 1898; fourth, that of January, 1904; and fifth, that of March, 1905.

All the large floods occurred during the spring or winter months and were due to rapid melting of snow. The largest summer flood was in August, 1888. The maximum stage was 32.2 feet and the rate of flow was 246,400 second-feet. That is about 0.6 the rate of the maximum spring flood.

The river stood above the danger line for four days, from the 6th to the 9th, inclusive, during the flood of 1884, and for three days, March 21 to 23, during the flood of 1905.

The total flow for the four days comprising February 6–9, 1884, less the total flow for these days at the danger line (36 feet) is about 802,100 acre-feet. The total flow for the three days comprising March 21–23, 1905, when this stream was above the danger line, less the total flow for the same period at the danger line, is about 357,000 acre-feet. These figures show approximately the storage necessary to prevent this stream from passing the danger line at this place during floods.

The following table gives the highest stage each year, from 1860 to 1905, at Cincinnati, Ohio, for the years that the river rose above 50 feet on the gage:

Flood stages of Ohio River at Cincinnati, Ohio.

[Danger line, 50 feet of gage; lowest stage, 1.9, September 17-19, 1881.]

Year.	Date.	Stage.	Year.	Date.	Stage.	Year.	Date.	Stage.
		Feet.			*Feet.*			*Feet.*
1832..	February 18.....	64.3	1880.	February 17.....	53.2	1893.	February 20......	54.9
1847..	December 17.....	63.6	1821.	February 16.....	50.6	1897.	February 26......	61.2
1862..	January 24.......	57.3	1882.	February 21.....	58.6	1898.	March 29..........	61.4
1865..	March 7..........	56.3	1883.	February 15.....	66.3	1899.	March 8..........	57.2
1867..	March 14.........	55.8	1884.	February 14.....	71.1	1901.	April 27..........	59.7
1870..	January 19.......	55.3	1886.	April 9..........	55.8	1902.	March 5..........	50.9
1875..	August 6.........	55.3	1887.	February 5......	56.3	1903.	March 5..........	52.3
1876..	January 29.......	51.8	1890.	March 26........	59.2	1905.	March 13.........	48.3
1877..	January 20.......	53.8	1891.	February 25.....	57.3			

In these forty-six years the river at this place rose above 50 feet on the gage twenty-three times. It has been at stages from 0.7 to 0.8 of the maximum stage fifteen times; at stages from 0.8 to 0.9 of the maximum stage six times; and at stages from 0.9 to 1 of the maximum stage twice. In the seventy-four years, from 1832 to 1905 there have been three floods, reaching stages from 0.9 to 1 of the maximum stage.

FLOOD ON GRAND RIVER, MICHIGAN.

This flood, although not so large as that of March, 1904, was probably the largest summer flood recorded in the history of this stream. The following table, taken from the United States Monthly Weather Review for June, 1905, gives the precipitation for May and for June 1 to June 6 at ten places in this drainage basin:

Precipitation in the basin of Grand River and its tributaries in May and June, 1905, in inches.

Station.	River.	May.		June.						
		Amount.	Departure from normal.	1.	2.	3.	4.	5.	6.	Total
Jackson	Grand	6.12	+2.49	0.03	Tr.	0.24	0.78	2.15	0.79	3.99
Fitchburg	Cedar	6.37	+2.01	Tr.	0	0	0.28	0.40	3.15	3.83
Webberville	do	4.36		0	0	0	0.10	1.13	4.76	5.99
Agricultural College.	do	5.17	+1.95	0	0	0	0.11	0.45	5.47	6.03
Lansing	Grand	5.51	+1.98	0	0.01	0	0.18	0.28	4.92	5.39
St. Johns	Looking Glass	5.46	+2.37	0	0	0	0.04	2.18	3.90	6.12
Charlotte	Thornapple	3.79								3.50
Hastings	do	6.60	+3.22	0	0	0	0.68	0.50	3.60	4.78
Ionia	Grand									6.31
Grand Rapids	do	5.97	+2.49	0	0.20	0	0.36	1.20	3.56	5.32
Average		5.48	+2.36	Tr.	0.03	0.03	0.32	1.04	3.77	5.13

The rainfall for May exceeded the normal by 2.36 inches, so that the ground was full or nearly so at the time of this flood. From the 4th to 6th of June 5.13 inches of rain fell; of this amount 75 per cent fell on the 6th.

The following table gives the daily gage height at Grand Rapids, Mich., from June 5 to June 17, and the daily gage height and corresponding discharge at this place during the flood of March, 1904:

Flood flow of Grand River at Grand Rapids, Mich., in 1904 and 1905.

[Drainage area, 4,900 square miles.]

Year.	Date.	Gage height.	Discharge.	Year.	Date.	Gage height.	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1904	March 20	9.20	16,700	1904	April 6	11.20	20,700
	March 21	9.30	17,000		April 7	10.50	18,800
	March 22	10.65	19,500		April 8	9.55	17,400
	March 23	11.45	21,400	1905	June 5	2.65	4,598
	March 24	15.60	30,300		June 6	10.6	18,820
	March 25	18.09	35,800		June 7	14.2	31,140
	March 26	19.05	37,800		June 8	18.1	47,990
	March 27	19.75	39,400		June 9	18.4	49,340
	March 28	19.36	38,500		June 10	17.7	46,100
	March 29	18.22	36,000		June 11	16.5	40,580
	March 30	16.77	32,900		June 12	15.3	35,425
	March 31	15.40	29,900		June 13	13.8	29,560
	April 1	14.45	27,800		June 14	12.5	24,850
	April 2	13.80	26,600		June 15	11.2	20,450
	April 3	13.80	26,600		June 16	9.9	16,770
	April 4	13.80	26,600		June 17	8.7	13,930
	April 5	12.80	24,500				

This stream rose rapidly on June 6, and reached a maximum of 18.4 feet on June 9. This flood, compared with that of March, 1904, was of shorter duration, more rapid rise and fall, and was 1.3 feet lower.

The lower part of the city of Grand Rapids was flooded. The damage done was small, compared with that of the flood of 1904, the difference in this respect being due largely to the timely warning of the height and progress of the flood given by the United States Weather Bureau.

The Muskegon and other streams in western Michigan were bank full, and in places overflowed lowlands and injured dams and bridges. Numerous washouts occurred on the railroads in western Michigan. The Pere Marquette reported thirty, some of them 200 feet long.

The streams in eastern Wisconsin, especially the Fond du Lac, were out of their banks as a result of the storm of June 6. A portion of Fond du Lac was flooded. Some washouts were reported on the Wisconsin Central and five on the Chicago and Northwestern.

The Sheboygan River was out of its banks at Sheboygan Falls, and caused damage in the low part of the town, and the Chippewa River overflowed at Eau Claire.

FLOOD IN EASTERN MISSOURI.

Heavy rains in Missouri and southern Illinois from September 15 to September 19 caused the Missouri River from Boonville to Hermann, Mo., to rise above the danger line, and some of the smaller streams of Missouri to be in destructive flood. The flood was remarkable for the time of year of its occurrence and the rapidity of its rise. The rain causing the flood occurred from the 15th to the 19th, but the larger part fell on the 17th. At Boonville, Mo., 12.98 inches fell from the 15th to the 19th. At Chester, Ill., 8.06 inches fell in 20.5 hours.

The streams rose very rapidly on the 17th. The following table gives the daily gage height of Meramec River at Meramec, the daily gage height and discharge of Meramec River at Eureka, Mo., and the gage height of the Gasconade River at Arlington, Mo., during this flood.

Flood flow of Meramec and Gasconade rivers during flood of September, 1905.

Date.	Meramec River, Meramec, Mo.	Meramec River, Eureka, Mo.		Gasconade River Arlington, Mo.
	Gage height.	Gage height.	Discharge.	Gage height.
	Feet.	*Feet.*	*Sec.-feet.*	*Feet.*
September 16	2.7	4.9	2,180	3.95
September 17	7.0	18.4	23,840	13.8
September 18	8.2	20.9	28,930	12.5
September 19	7.8	24.5	37,640	16.5
September 20	6.0	29.7	51,160	13.6
September 21	5.6	28.5	48,040	14.0
September 22	5.1	24.5	37,640	10.4
September 23	4.3	13.5	14,040	7.4
September 24	4.2	7.4	4,950	6.3
September 25	3.9	6.6	4,030	5.8
September 26	3.7	5.9	3,260	5.8

Gasconade River rises in the southeastern part of Missouri, flows in a general northeasterly direction, and empties into the Missouri River about 6 miles west of Hermann, Mo. It is a very crooked stream, with little fall. The basin is mainly hilly or rolling land, cultivated or grass covered. The area of this basin above the gaging station at Arlington is 2,725 square miles.

Meramec River rises in the eastern part of Missouri, flows in a general northeasterly direction, and empties into the Mississippi about 22 miles below St. Louis. The drainage basin is hilly or rolling, cultivated or grass-covered land, and comprises an area of 3,619 square miles. The area above the gaging station at Eureka is 3,497 square miles.

The maximum daily rate of the Meramec at Eureka during this flood was 51,160 second-feet, or about 14.63 second-feet per square mile.

During the flood of January, 1897, the Gasconade at Arlington reached a stage of 26.90 feet—that is, a stage nearly twice as high as that reached by it during the flood of 1905.

The following table shows the daily gage heights at four United States Weather Bureau stations—Boonville, Hermann, Grafton, and St. Louis—two on Missouri River, and two on Mississippi River. Boonville is 199 miles above the mouth of the Missouri; Hermann is 103 miles above the mouth; Grafton is on the Mississippi about 21 miles above the mouth of the Missouri, and St. Louis is about the same distance below.

Stages of Missouri River during flood of September, 1905.

Date.	Missouri River.		Mississippi River.	
	Boonville, Mo.[a]	Hermann, Mo.[b]	Grafton, Mo.[c]	St. Louis, Mo.[d]
	Feet.	*Feet.*	*Feet.*	*Feet.*
September 15	8.8	9.7	8.2	11.3
September 16	10.6	11.2	8.2	11.1
September 17	16.9	20.7	8.8	12.9
September 18	21.3	24.3	11.0	23.2
September 19	21.6	25.4	13.6	27.1
September 20	22.0	25.4	15.6	29.3
September 21	21.3	24.6	16.4	30.2
September 22	19.5	23.3	16.2	30.1
September 23	17.9	21.6	15.2	29.2

[a] Lowest recorded stage, −0.6 feet.
[b] Lowest recorded stage, 0.0 feet.
[c] Lowest recorded stage, −0.3 feet.
[d] Lowest recorded stage, −2.5 feet.

Some lowland along Missouri River was flooded and crops were damaged. Several of the smaller streams overflowed their banks, washed away some of the smaller bridges, and interfered with railway traffic for several days.

FLOODS IN SOUTH DAKOTA.

Freshets occurred on some of the streams of South Dakota in June, July, and August. The damage done was confined mainly to the Teton or Bad River in the vicinity of Fort Pierre. Heavy rain on July 2 and 3 caused this river to overflow its banks in a flood that swept away 17 houses and drowned 7 persons. There is no gaging station on this stream and the United States Weather Bureau gage at Pierce was carried away by the flood, so that records of river stage and rate of flow are not available for points in the eastern part of the State. There are several gaging stations in the western part of South Dakota, however, and data obtained there show magnitude of the floods in that part of the State.

The following table gives the gage heights during these freshets at gaging stations on the Cheyenne at Edgemont, the White at Interior, the Moreau at Bixby, and the Grand at Seim, and also the daily rate of flow at Edgemont:

Stages and flow of streams of South Dakota during freshets of June-August, 1905.

Date.	Cheyenne River at Edgemont.		White River at Interior.	Moreau River at Bixby.	Grand River at Seim.
	Gage height.[a]	Discharge.	Gage height.[b]	Gage height.[c]	Gage height.[d]
	Feet.	*Sec.-feet.*	*Feet.*	*Feet.*	*Feet.*
June 17	5.45	2,752	4.2	3.0	3.6
June 18	9.65	9,175	16.0	6.75	4.0
June 19	4.4	1,850	6.0	6.40	4.9
June 20	....	....	....	4.8	4.6
July 1	2.7	345	3.75	1.7	2.2
July 2	9.35	8,665	9.20	2.1	2.2
July 3	5.80	3,460	13.50	6.1	4.0
July 4	....	....	10.10	5.3	3.6
July 5	....	....	8.3	....	....
July 19	2.1	75	2.35	3.3	2.6
July 20	7.7	6,280	4.05	3.1	2.8
July 21	5.9	3,595	2.95	2.15	2.9
July 28	6.0	3,730	4.25	2.25	2.1
July 29	10.7	10,960	9.50	1.9	2.6
July 30	9.7	9,260	7.00	1.8	2.4
July 31	6.0	3,730	6.30	1.75	2.1
August 5	2.95	562	3.35	1.5	2.1
August 6	7.95	6,842	3.05	1.5	2.0
Auguts 7	4.0	1,420	2.85	1.5	1.9
August 11	5.0	2,440	2.15	1.4	1.8
August 12	8.4	7,420	5.20	1.4	1.8
August 13	5.8	3,460	5.15	1.6	1.8

[a] Lowest reading, 1.4.
[b] Lowest reading, 1.6.
[c] Lowest reading, 1.0; discharge, 0.
[d] Lowest reading, 1.5.

These four streams drain the western half of South Dakota, flow in a general easterly direction, and empty into Missouri River. Seim is about 90 miles from the western boundary of the State, Bixby 72 miles, Edgemont 11 miles, and Interior 100 miles. The drainage area above Edgemont is 7,350 square miles; above Bixby, 1,600 square miles.

As the table shows, there were six freshets on the Cheyenne during the year—one in June, three in July, and two in August, the largest of the six being the fourth, during which the daily rate of discharge was 10,960 second-feet, or about 1.5 second-feet per square mile of drainage above station. These floods were of short duration, the high water lasting only a day.

During only three of these six flood periods did the flow of White River at Interior rise more than 5 feet above low water. The flood of June was the largest of the three on the White, the stage on the 18th being about 14.5 feet above low water.

During these flood periods the stage of the two streams in the northwestern part of the State—the Moreau and the Grand—was less than 6 feet above low-water.

FLOOD IN SOUTHEASTERN MINNESOTA.

Heavy rains in Minnesota from July 3 to July 6 caused the upper Mississippi to reach a stage of 14.8 feet at St. Paul, Minn., the highest since 1897. The flood of April, 1881, reached a stage of 19.7 feet.

The following table gives the daily gage heights of the Mississippi River at Sauk Rapids, Minn., during the freshet; also the gage height and rate of flow of two of the tributaries, the Minnesota, which enters from the west at St. Paul, and the Chippewa, which enters from the north 70 miles below St. Paul:

Flow of upper Mississippi River and tributaries during the freshet of July, 1905.

Date.	Chippewa River at Eau Claire, Wis.[a]		Minnesota River at Mankato, Minn.[b]		Mississippi River at Sauk Rapids.[c]
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*
July 5	6.9	8,390	9.4	9,400	18.8
July 6	10.4	18,960	10.6	11,310	19.8
July 7	10.6	19,640	11.7	13,070	20.1
July 8	11.3	22,050	12.2	13,870	20.2
July 9	10.1	17,940	12.5	14,350	20.1
July 10	7.0	8,650	12.0	13,550	19.6
July 11	8.1	11,740	11.8	13,230	19.2
July 12	6.9	8,390	11.2	12,270	18.6

[a] Lowest stage during 1905, 4.1 feet; discharge, 2,010 second-feet.
[b] Lowest stage during 1905, 1.80 feet; discharge, 750 second-feet.
[c] Lowest stage during 1905, 11.25 feet.

The Chippewa at Eau Claire reached a stage of 19.6 feet and a discharge of 60,520 second-feet on June 8, 1905, and the Minnesota at Mankato, Minn., reached a stage of 19.6 feet on May 29, 1903, so that the greatest stage reached by the flood of July, 1905, on these streams was far below the highest recorded stages at these places.

FLOOD ON DEVILS CREEK, IOWA.

By E. C. Murphy and F. W. Hanna.

INTRODUCTION.

Lee County, in southeastern Iowa, and Hancock County, in western Illinois, which borders Lee County on the east, were visited by a very heavy rain storm during the night of June 9, 1905. As a result of this storm the streams in these counties rose to extraordinary heights, causing great damage to property. Railroads, highways, and bridges were severely injured, stream beds and banks were badly scoured in many places, and débris was transported and deposited throughout the creek valleys, destroying crops and damaging many acres of valuable land.

The data on which this report is based were obtained by investigating the conditions on the ground about one month after the flood, through facilities afforded by the courtesy of the engineers of the Santa Fe Railway. Owing to the lapse of time between the storm and the examination of its results the information obtained is necessarily incomplete.

The area affected by this storm is in the central Mississippi drainage basin. Devils Creek, the stream on which most of the damage was done, drains directly into the Mississippi a few miles below Fort Madison, Iowa. It rises in Marion and Cedar townships and flows in a general southeasterly direction for about 20 miles. Panther Creek, the largest

western tributary of Devils Creek, rises in the southern part of Franklin township, flows in a general southeasterly direction about 8 miles, and joins the main stream about 3 miles above its mouth. It drains an area of 14 square miles. The principal tributary of Devils Creek is Little Devils Creek, which enters it about 1 mile below the junction of Devils and Panther creeks. It is 7 miles long and drains an area of 19 square miles. The drainage area of Devils Creek and that of the lower part of each of these two tributaries consists of alluvial, sandy soil that erodes readily. The upper drainage area is covered with heavy

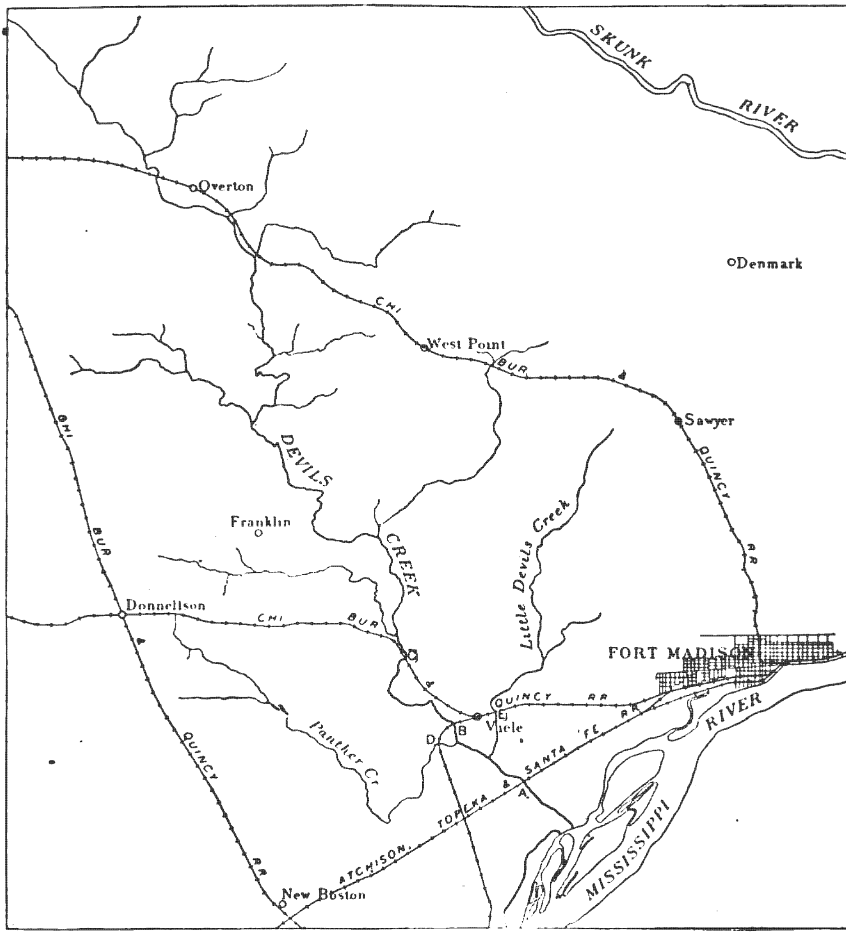

FIG. 5.—Map of drainage basin of Devils Creek, Iowa.

clay soil. There is little timber in the basin except narrow strips in places along the creeks. The total drainage area of Devils Creek and its branches at its mouth is about 145 square miles, while that at the Santa Fe Railway bridge is about 143 square miles.

PRECIPITATION.

The storm causing the damage here discussed is described in the June issue of the Monthly Review of the Iowa Weather and Crop Service, as follows.

On the afternoon and night of June 9 and morning of the 10th copious showers visited all districts, and in a considerable portion of the southeast and east-central districts the downpour can only be described by the term "torrential." The heaviest amounts reported at stations in the submerged

section were as follows: Bonaparte, 12.10 inches; Keosauqua, 11.09; Stockport, 10.63 (three cooperative stations in Van Buren County); Mount Pleasant, 7.20; Burlington, 6.10; Fort Madison, 6.40; Keokuk, 4.80; Chariton, 4.22; Albia, 3.44; Iowa City, 4.87; Amana, 3.65; Davenport, 5.67; Wilton, 4.17; Le Claire, 4.41 inches. The larger part of this heavy precipitation fell in the twelve hours from 8.30 p. m. of the 9th to 8.30 a. m. of the 10th, and in Bonaparte the average downpour was about an inch an hour. The result of such a shower may be imagined but can not be fully described in detail. Not many buildings were sufficiently well roofed to keep the occupants dry, and but few streams and water courses were adequate to carry off the surplus moisture. Those who were driven into the wet say it came down in sheets and hit so hard it was difficult to stand, though there was no wind. One of the Van Buren County reporters states that 85 county bridges were swept away. The aggregate damage to crops by erosion of soil on slopes and flooding the bottoms was altogether beyond estimation in all the area swept over by that unprecedented storm. Happily such storms are not usual visitations.

The following table, prepared from data furnished by the United States Weather Bureau, shows the depth of rainfall in inches at several surrounding places in Iowa and Illinois:

Precipitation at places in southeastern Iowa, June 9, 10, and during June, 1905, in inches.

Place.	June 9.	June 10.	Total for June.
Davenport, Iowa	3.93	1.69	7.68
Dubuque, Iowa	1.20	.38	4.33
Hannibal, Mo	.17	1.95	2.71
Keokuk, Iowa	2.18	2.62	6.57
La Harpe, Ill	.00	10.25	12.60

THE FLOOD.

Devils Creek at the Santa Fe Railway bridge began to rise about 10 p. m. and continued to rise gradually until about 12.30 a. m., when, according to the report of the bridge watchman, it rose about 4 feet in fifteen minutes. The bridge and about 150 feet of the right embankment went out about 4 a. m., when the water reached its maximum height, 17.7 feet above low water. This bridge was a Pratt truss bridge of 149-foot span, resting on masonry piers, with 54 feet of pile approach on the right side and 109 feet on the left. Fig. 6 shows a plan of this stream in the vicinity of the bridge; also a cross section and profile taken June 24, 1905, fourteen days after the flood. The waterway below the high-water line of June 10 had an area of 4,320 square feet before the flood and about 13,000 square feet after the flood. Thus it seems that the scouring effect at this bridge increased the waterway to three times its original size.

The daily gage heights and corresponding discharges at the United States Geological Survey gaging station on Des Moines River at Keosauqua, Iowa, from June 9 to 14, inclusive, were as follows:

Gage heights and discharge of Des Moines River at Keosauqua, Iowa, June 9-14.

Date.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*
June 9	4.0	8,550
June 10	22.8	75,750
June 11	14.4	44,670
June 12	10.6	30,610
June 13	8.1	21,460
June 14	5.6	13,250

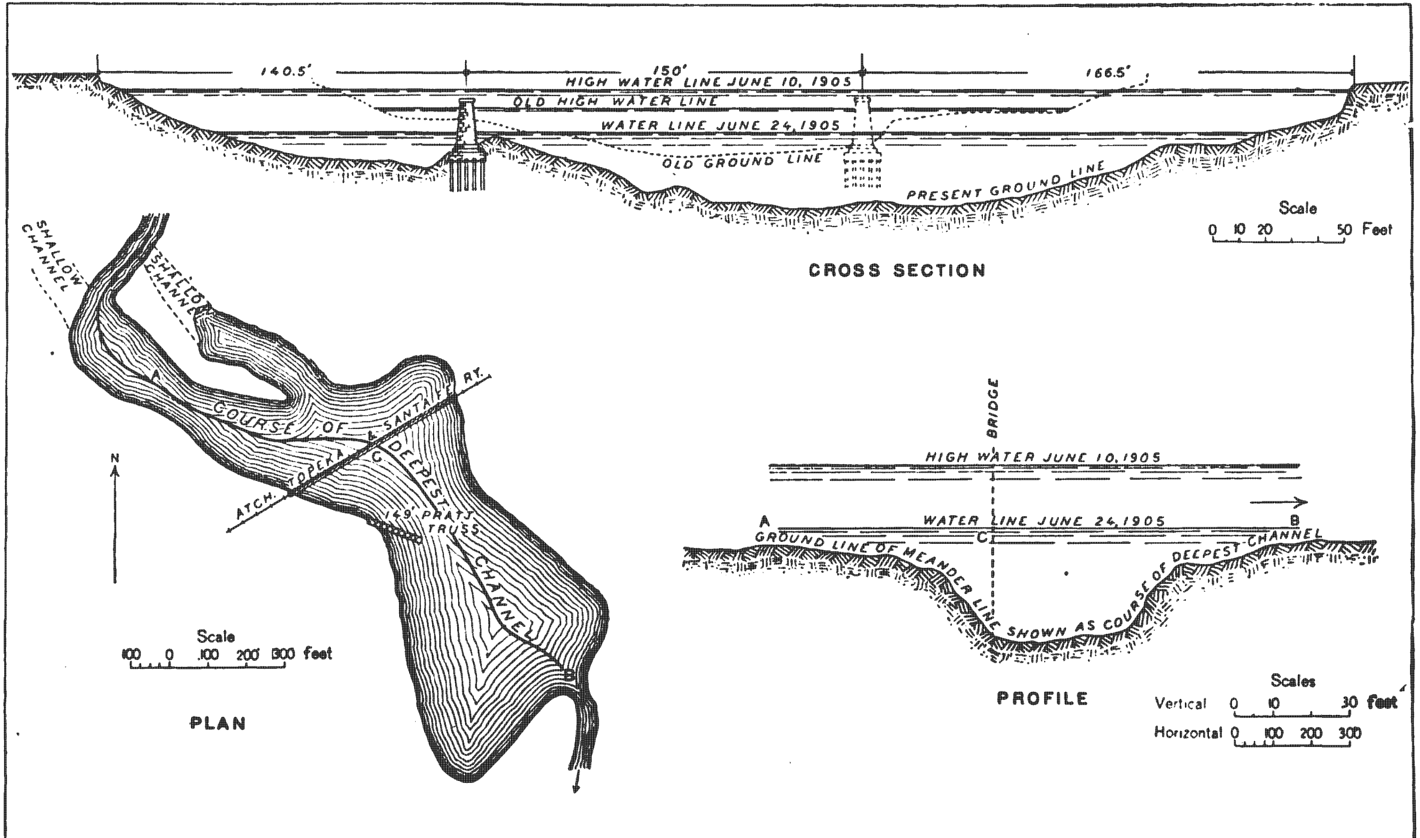

FIG. 6.—Plan and profile of Devils Creek at Atchison, Topeka and Santa Fe Railway crossing.

The table shows that the river at Keosauqua station rose from 4 feet on the 9th to 22.8 feet on the 10th, a total rise of 18.8 feet. Des Moines River at Des Moines rose on the 10th about 1 foot. Iowa River at Iowa City rose from 2.2 to 7.7 feet on the 10th. There was no rise on the 10th either in Cedar River at Cedar Rapids, Iowa, or in Rock River at Sterling, Ill. Skunk River is reported to have been very high, but there is no record of the amount of rise. Mississippi River at Fort Madison, Iowa, rose from 8 feet on the evening of the 9th to 11 feet on the morning of the 10th. The gage on the Mississippi River at Keokuk, Iowa, read 18.4 feet at 2 p. m. on the 10th. The maximum stage here in 1888 was 19.95 feet, the maximum in 1903 was 19.6 feet, and the maximum during the great flood of 1851 was 21.05 feet.

The high-water marks on Devils Creek show that the height of the flood and the flow were much greater on this creek than on either Panther or Little Devils Creek. The maximum rate of flow of this stream during this flood is very difficult to compute because it overflowed its banks and was from a quarter to a half a mile in width, except at some of the bridges. At the Santa Fe bridge Devils Creek was ultimately about 470 feet wide, but the stream bed was so much scoured that the cross section affords no basis for determining the size of the stream when the flow was at its maximum. Mr. Gray, the Santa Fe engineer in charge of the construction work at this bridge at the time of the flood, believes that the stream bed, which is of sand, scoured down to the clay previous to the time the bridge failed. The high-water marks above and below this bridge indicate a slope of 0.0025. The coefficient of roughness has been assumed to be 0.050. This high coefficient of roughness is necessary, owing to the many obstructions in the stream at the bridge. The channel is extremely crooked and the banks are covered with trees immediately above the bridge. The amount of pier and piling at the bridge was great, there being, in addition to the two piers on which the iron truss was supported, 54 feet of pile approach on one side and 109 feet on the other.[a] Undoubtedly immense amounts of drift were collected in and about these piers and piles. In addition to this there must be taken into consideration the effect of constriction of channel, for the stream immediately above the bridge was two or three times as wide as at the bridge. The hydraulic mean depth has been roughly computed from the maximum area to be 27.3 feet. From these data and the use of Kutter's formula, c being 56, v is found to be 14.6 feet per second; and the maximum rate of discharge is approximately 189,800 second-feet computed from the maximum cross-section area. Inasmuch as the drainage area of Devils Creek at the Santa Fe bridge is 143 square miles, this gives an approximate maximum run-off of 1,300 second-feet per square mile.

In order to verify this computation, an attempt has been made to compute, by means of Kutter's formula, the flow of the tributaries of Devils Creek. Considerable care has been exercised in selecting the proper coefficients of roughness and although at first they may seem somewhat large, yet an investigation of the conditions at the cross sections will show that they are proper. From data obtained at the Chicago, Burlington and Quincy Railway crossing on Devils Creek the maximum rate of discharge was found to be 161,600 second-feet, with a slope of 0.005 and a coefficient of roughness of 0.050; that at the crossing on the same line on Little Devils Creek was found to be 10,700 second-feet, with a slope of 0.002 and a coefficient of roughness of 0.040; and the maximum rate of discharge at the crossing of the Chicago, Burlington and Quincy Railway bridge on Panther Creek was found to be 7,300 second-feet, with a slope of 0.0028 and a coefficient of roughness of 0.038. The sum of these discharges is 179,000 second-feet. The drainage area of Devils Creek at the Santa Fe bridge exceeds the sum of the areas represented by the three points selected by about 2 square miles. Adding for this excess drainiage area 1,300 second-feet per square mile to the discharge found by the summation of the partial discharges, there would be at the Santa Fe bridge over Devils Creek a discharge of 182,000 second-feet, which differs from the original computation by about 4 per cent.

[a] See Ganguillet and Kutter, flow of water, Theiss below Szolnok, Class B, Division VIII.

It has been noted that the run-off per square mile on the drainage area of Devils Creek at the Santa Fe bridge is about 1,300 second-feet. Like computations show that the run-off per square mile is about 1,500 second-feet, 560 second-feet, and 520 second-feet for Devils Creek, Little Devils Creek and Panther Creek, respectively, at points near Viele. This clearly indicates that the flood was concentrated in the main Devils Creek Valley.

These maximum rates of flow are greatly in excess of any that have been published for streams in the United States, and although the data were obtained with care they may be in error by a large amount. There was no engineer on the ground during this flood from whom definite information could be obtained as to what happened at each measured section at the time of maximum flow. Drift undoubtedly lodged in front of the Santa Fe Railway bridge and abutments, making a difference in elevation of the water surface above and below the bridge, and consequently a greater surface slope than the stream would show during times of free flow. Again, it is impossible to state with certainty the rate of scour of the bed and banks. The computed rate of flow is based on the area obtained from soundings taken on June 24, fourteen days after the flood. This area is three times larger than the area at this place just prior to the flood.

The behavior of Devils Creek at the bend (fig. 6), 1.5 miles above Viele, well illustrates the change of velocity in the channel around a bend when overflow takes place across the bend. This stream makes a sharp bend about 1,000 feet above the Chicago, Burlington and Quincy Railway bridge and flows nearly parallel with the railway. The overflow cut across this bend and entered the channel below with a velocity which was greater than that in the channel because of the same fall in a shorter distance. The entry of this overflow produced backwater in the channel above, reducing the velocity almost to zero. The overflow across the bend carried a steel bridge over the railway embankment, washed away the track, and eroded the embankment to a depth of 10 feet, but although the water was 3 feet deep on the railway bridge, the bridge was not damaged.

DAMAGE.

The damage done was very large considering the small area covered by the storm. In addition to the damage done at the Santa Fe Railway bridge No. 342, already mentioned, the Chicago, Burlington and Quincy Railway bridge over Devils Creek at Viele was swept away, with 375 feet of the right approach, and the abutments of the railway bridges over Little Devils and Painter creeks near Viele were badly damaged and 900 feet of embankment washed away. Besides these, 14 county bridges over Devils Creek in Lee County, varying in length from 70 to 127 feet; 6 bridges over the branches of Devils Creek, of lengths ranging from 30 to 156 feet; 4 bridges over Little Devils Creek, of lengths ranging from 110 to 136 feet; and 3 bridges over Panther Creek, of lengths ranging from 90 to 156 feet, were either swept away or damaged. The cost of replacing these county bridges was estimated at $27,000 by M. E. Bannon, bridge engineer, Lee County, Iowa. Many small bridges in this county were also swept away, and several miles of road and several acres of land were badly damaged by scour or by deposit of sand and débris upon it.

INFERENCES FROM FLOOD.

The general inference to be drawn from the effects of the high water on bridges throughout Devils Creek Valley is that all the waterways were by far too small. The waterways on the main stream were not more than one-third the size required to carry with safety the immense volume of water flowing at the time of the maximum stage. However, that it would not be economical and, therefore, not good engineering practice, to attempt to provide waterways sufficient for such extraordinary floods as that of June 10, 1905, is certain. The long lapse of time between storms of such abnormal proportions as the one here described makes the interest on the invested capital of the structure exceed several times the cost of replacement. The most economical bridge is one whose waterway is based on a careful study of the frequency and intensity of storms and the corresponding run-offs with a view to balancing interest on the first cost against cost of replacement, loss of traffic, etc., due to washouts.

Such engineering study is unfortunately hindered by lack of comprehensive data concerning rainfall. The washout experience of the railroads at their crossings on Devils Creek should result in enlargements of their waterways. That the new waterways need not be as large as the openings made by the flood, and that they should be larger than they were before the flood are equally without doubt.

The following table, taken from Table VI, Bulletin C, of the Weather Bureau, shows maximum rates of rainfall at points surrounding Lee County for periods prior to and including 1891.

Maximum rainfall at certain points in Mississippi River basin.

Location of station.	Period.	Maximum in 72 hours.	Maximum in 48 hours.	Maximum in 24 hours.
	Years.	*Inches.*	*Inches.*	*Inches.*
Dubuque, Iowa	32	5.8	5.4	4.5
Keokuk, Iowa	20	5.5	5.3	4.8
Omaha, Nebr	22	5.5	5.4	5.0
St. Louis, Mo	52	6.7	6.7	4.5
Cairo, Ill	20	5.7	5.2	4.2
St. Paul, Minn	22	5.1	4.6	3.7
Indianapolis, Ind	22	6.4	6.0	4.3

This table indicates that a rainfall of about 5 inches in twenty-four hours may be expected to occur at least as often as once in twenty years. It would therefore, seem wise to provide waterways for such storms as far as possible. It is a matter of record, as shown by the table below, that the major portion of the precipitation in these cases occurs in a few hours, and is not equally distributed throughout the twenty-four-hour period. It is also a well-known fact that as a rule these great rainstorms are local.

Heavy precipitation in upper Mississippi Valley.

Place.	Date.	Precipitation.	Time.
		Inches.	*h. m.*
Bright, Ind	September 23, 1898	2.00	2
Kansas City, Mo	August 17, 1898	1.97	2
Omaha, Nebr	July 6, 1898	0.98	1 53
Wheatland, Mo	July 29, 1898	2.54	2
Oberlin, Kans	July 6, 1898	3.30	2
Dresden, Kans	July 5, 1898	2.63	2
Shelbyville, Ind	July 25, 1898	2.33	2
Avalon, Mo	June 26, 1898	3.00	2
Englewood, Kans	June 14, 1898	2.30	2
Vevay, Ind	June 9, 1898	3.00	2
Tilden, Ill	June 16, 1898	2.05	2
Campbell, Kans	April 30, 1898	3.00	2
Hannibal, Mo	March 26-27, 1889	2.90	2
St. Louis, Mo	March 18, 1898	1.52	1 20
Columbia, Mo	October 28, 1900	1.92	1 20
St. Paul, Minn	September 11, 1900	1.39	1 20
Kansas City, Mo	September 27, 1900	1.33	1 20
Omaha, Nebr	June 16, 1900	2.19	1 20
Evansville, Ind	June 14 and 15, 1900	1.36	1 20
St. Paul, Minn	August 9, 1902	3.04	1 20
Columbia, Mo	August 18, 1902	2.04	1 20
Kansas City, Mo	July 1, 1902	3.37	1 20
Kansas City, Mo	August 13, 1903	1.35	2

Let it be assumed, for streams with small drainage areas, that 60 per cent of the twenty-four-hour rainfall occurs in two hours; that it takes two hours for the storm water from the remotest part of the drainage area to reach a given point, and that the proportion of run-off is 70 per cent, for the per cent of run-off is often very large during heavy rains, as the ground is likely to be already thoroughly saturated. The amount of water reckoned in second-feet arriving at the lower end of this drainage area at the end of a two-hour period would be the total precipitation in cubic feet on that area for one second. Now, if F equals the number of square feet in a square mile; M, the member of square miles in the drainage area; P, the precipitation in feet for two hours; R, the percentage of run-off; T, the number of seconds in two hours, and Q, the maximum drainage area run-off; then,

$$Q=\frac{F\,M\,P\,R}{T}.$$

By substitution,

$$Q=\frac{5280\times 5280\times \frac{3}{12}\times .70\ M}{2\times 60\times 60}=678\ M.$$

That is, there would be 678 second-feet per square mile to provide for. Evidently the rate of precipitation to be used should be the maximum occurring in the time required for the remotest waters to reach the point considered.

FLOOD IN DES MOINES COUNTY, IOWA.

On the night of August 15, 1898, a storm of great intensity occurred in Des Moines County, Iowa. [a] This storm and the damage done by it are discussed by Maurice Ricker in a paper entitled "The August Cloudburst in Iowa," read before the Iowa Academy of Sciences, December 28, 1898. This storm was confined to about two-thirds of Des Moines County, or an area of about 250 square miles. Unfortunately there were no rain gages in this area, but Mr. Ricker claims that reliable measurements of the depth of water in empty cans in exposed places indicate that over an area of about 50 square miles the precipitation was about 16 inches.

Twenty-three county bridges were swept away by this flood, and the Burlington, Cedar Rapids and Northern Railway lost 5 bridges and 2 miles of track by it.

FLOOD ON PURGATORY RIVER, COLORADO.

From April 22 to 24, 1905, 2.5 inches of rain and snow fell at Trinidid, Colo., and a greater depth on the mountains, causing a freshet in Purgatory River for several days. The stream has a fall of 42 feet per mile in the vicinity of Trinidad, and the sandy loam banks, softened by the rains, disappeared rapidly into the river. Many acres of fertile bottom land and thousands of feet of railway were swept away. The stream in places shifted its channel from one side of the valley to the other, necessitating the moving of some of the bridges.

Pl. I is a view of the river above Trinidad. On the right is a bridge, under which the river passed before the flood of September, 1904. The road and the right bank for several hundred feet were washed away. The railroads passing through Trinidad suffered heavily from these floods. All the trains on the Atchison, Topeka and Santa Fe Railway from Kansas City to the Southwest were delayed for several days. Large gangs of men were kept constantly at work repairing and rebuilding track washed out by the high water. About 2,000 feet of the pipe line that supplies the city of Trinidad with water were washed out, and the city was left without drinking water for several days.

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[a] Monthly Review of the Iowa Weather and Crop Service, December, 1898.

The following table gives the gage heights and daily rate of flow of this stream at the gaging station near Barela, Colo., 30 miles below Trinidad and about one-eighth of a mile below the canyon entrance:

Flood flow of Purgatory River at entrance of canyon, Barela, Colo., April 23 to May 5, 1905.

Date.	Hour.	Gage height.	Hour.	Gage height.	Mean gage height.	Discharge.
	a. m.	*Feet.*	*p. m.*	*Feet.*	*Feet.*	*Sec.-feet.*
April 23	8.45	4.90	....	....	4.90	261
April 24	8.00	8.60	1.00	8.00		
April 24	9.00	8.40	2.00	7.90		
April 24	10.00	8.20	3.00	7.80	8.08	1,528
April 24	11.00	8.10	4.00	7.75		
April 24	12.00	8.10	5.00	7.70		
April 25	8.45	7.35	1.45	7.60		
April 25	9.45	7.35	2.45	7.90		
April 25	10.45	7.35	3.45	8.40	7.96	1,456
April 25	11.45	7.40	4.45	9.20		
April 25	12.45	7.45	5.45	9.50		
April 26	8.00	9.80	1.00	9.70		
April 26	9.00	9.80	2.00	9.65		
April 26	10.00	9.80	3.00	9.60	9.72	2,676
April 26	11.00	9.75	4.00	9.65		
April 26	12.00	9.70	5.00	9.65		
April 27	7.30	11.50	1.00	10.10		
April 27	8.30	11.30	2.00	10.00		
April 27	9.30	11.10	3.00	10.10	11.01	3,790
April 27	10.30	10.75	4.00	10.50		
April 27	11.00	10.50	5.00	10.90		
April 27	12.00	10.40	....	....	....	....
April 28	8.00	10.80	5.00	9.90	10.35	3,198
April 29	8.00	8.90	5.30	8.30	8.60	1,860
April 30	7.15	7.90	5.00	7.50	7.70	1,305
May 1	8.30	7.70	5.00	7.30	7.50	1,195
May 2	8.30	7.30	....	....	7.30	1,095
May 3	8.00	6.80	....	....	6.80	865
May 4	8.00	6.40	....	....	6.40	695
May 5	8.00	5.80	4.00	5.90	5.85	496

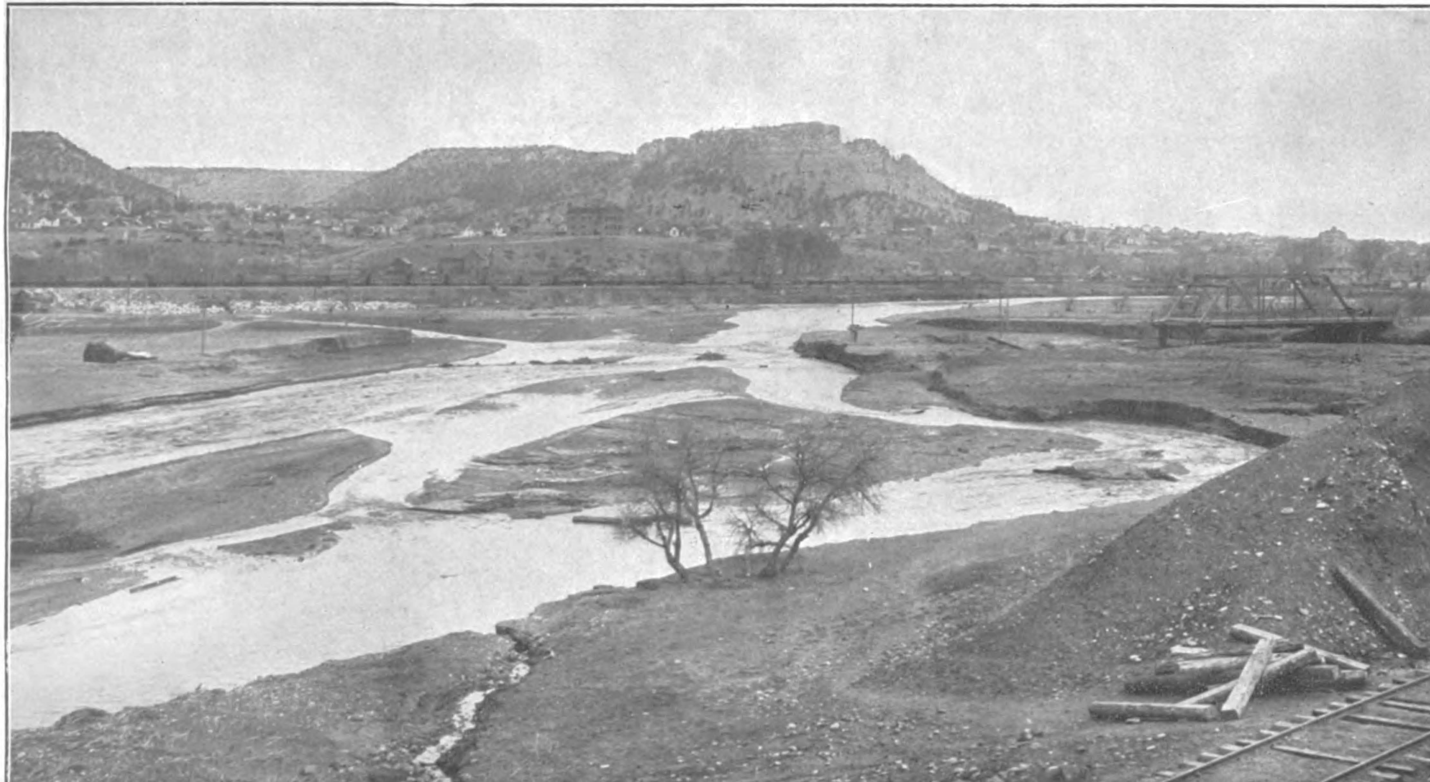
It is seen that the largest recorded gage height was 11.50 feet, on the morning of the 27th. The gage reader reports that on the night of the 26th the water reached the 15-foot mark on the gage. The discharge for a 15-foot stage is upward of 7,700 second-feet.

FLOOD ON PECOS RIVER, NEW MEXICO-TEXAS.

During the latter part of July a flood occurred on the Pecos River that approached closely in magnitude the great flood of September and October, 1904, in that part of the stream from Carlsbad, N. Mex., to Pecos, Tex. The flood did much damage to bridges and irrigation works.

Pecos River rises in the northern part of New Mexico, flows in a southerly and southeasterly direction a distance of 550 miles, and empties into the Rio Grande near Langtry, Tex.

The following table gives the daily gage height at Santa Rosa and Roswell and the daily gage height and corresponding discharge at Carlsbad and Pecos, Tex., during the flood.



PURGATORY RIVER AT TRINIDAD, COLO.

Daily rate of flow of Pecos River during floods of 1905.

Date.	Santa Rosa, N. Mex.	Roswell, N. Mex.	Carlsbad, N. Mex.		Pecos, Tex.	
	Gage height.[a]	Gage height.[b]	Gage height.[c]	Discharge.	Gage height.[d]	Discharge.
	Feet.	*Feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
July 20	0.7	3.3	0.99	206	0.9	140
July 21	0.9	3.0	1.48	476	0.9	140
July 22	2.5	3.0	1.54	518	0.9	140
July 23	1.5	10.0	2.77	1,504	1.0	150
July 24	1.5	6.0	8.67	18,620	4.9	1,600
July 25	1.5	6.7	[e]14.39	47,600	7.2	5,380
July 26	1.0	5.6	12.42	37,500	9.4	8,450
July 27	1.0	4.3	10.00	25,000	13.7	16,100
July 28	1.0	3.8	7.00	11,300	18.3	25,500
July 29	1.0	3.4	5.35	5,685	17.2	22,650
July 30	1.0	3.4	4.50	3,750	13.2	15,200
July 31	1.0	3.4	4.15	3,140	10.7	9,750
August 1					7.6	5,800
August 2					6.2	4,170

[a] Maximum stage during flood of October, 1904, 23 feet.
[b] Maximum stage during flood of October, 1904, 16.5 feet.
[c] Maximum stage during flood of October, 1904, 15+ feet.
[d] Maximum stage during flood of October, 1904, 19 feet.
[e] Gage height at 10 a. m., 15.85 feet; discharge, 54,930 second-feet.

It is seen that the stream above Santa Rosa was not in flood at this time, as the gage did not read above 2.5 feet, not within 21 feet of the gage reading of September 30, 1904. At Roswell the maximum stage was 7 feet; it was 16.5 feet on October 1, 1905. The maximum stage at Carlsbad occurred on July 25, and was at least 1.4 less than in October, 1904. At Pecos, Tex., the highest stage was reached on July 28, and was about a foot less than the highest stage in October, 1904. The Pecos did not begin to rise at the mouth until July 30. It rose slowly from a stage of 1.7 feet and a rate of flow of 670 second-feet on July 29 to a stage of 5.6 feet and a rate of flow of 5,530 second-feet on August 12.

The total run-off of the Pecos at Carlsbad, N. Mex., for the nine days, July 23–31, of this flood was 305,600 acre-feet.

By comparing the gage heights and corresponding rates of flow given in the table above with those prevailing during the flood of September and October, 1904,[a] it will be seen that the flood of 1905 was much smaller than the flood of 1904 above Carlsbad and almost disappeared above Santa Rosa. In the vicinity of Pecos, Tex., the flood of 1905 almost equaled in magnitude that of 1904, but was of shorter duration. The stage was 9 feet or more for twelve days in 1904 and only six days in 1905.

[a] See Water-Supply and Irrigation Paper, U. S. Geol. Survey, No. 147, p. 133.

FLOOD ON HONDO RIVER, NEW MEXICO.

The Hondo reached a higher stage at Hondo reservoir during 1905 than during 1904.

The following table gives the daily gage height and discharge at Hondo reservoir during the flood of 1905:

Daily rate of flow of Hondo River during floods of July, 1905.

Date.	Reservoir.		Roswell.	
	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
July 22	Dry.			
July 23	6.3	460		
July 24	8.05	820	4.1	422
July 25	11.4	1,790	5.0	551
July 26	9.2	1,115	5.7	660
July 27	8.55	950	4.9	535
July 28	7.0	600	4.85	528
July 29	6.5	500	3.6	358
July 30	4.15	170	2.95	280
July 31	4.35	250	2.25	202

FLOOD ON RIO GRANDE, NEW MEXICO-TEXAS.

INTRODUCTION.

From May 15 to June 20 the part of this stream between Albuquerque, N. Mex., and Presidio, Tex., was in destructive flood. The dikes protecting villages and lowlands were overtopped and considerable damage was done to crops, railway property, buildings, and land along the river. It was the spring flood, due to the rapid melting of an exceptionally large winter accumulation of snow on the mountains.

The Rio Grande rises among the mountains of southern Colorado, flows in a general southerly and southeasterly direction for about 1,800 miles, and empties into the Gulf of Mexico. Its two largest tributaries are the Pecos, entering from the north near Morehead, Tex., and the Rio Conchos, entering from the south at Presidio, Tex. (see fig 7). It is a storm-water stream, subject to large and sudden fluctuations of flow, except in the spring and early summer, when its water comes from melting snow in the mountains at the headwaters. The basin is long and comparatively narrow, the larger part being mountainous, with steep, barren, impervious slopes. From its head to Del Norte, Colo., a distance of 144 miles, the fall of the stream is 4,258 feet; from Del Norte to San Marcial, 393 miles, the fall is 3,342 feet; from San Marcial to El Paso, 203 miles, it is 700 feet; from El Paso to the mouth, 1,032 miles, it is 3,700 feet. The area of the watershed above El Paso is 38,000 square miles.

FLOOD FLOW.

There are eight gaging stations on this stream. The daily rate of flow and progress of

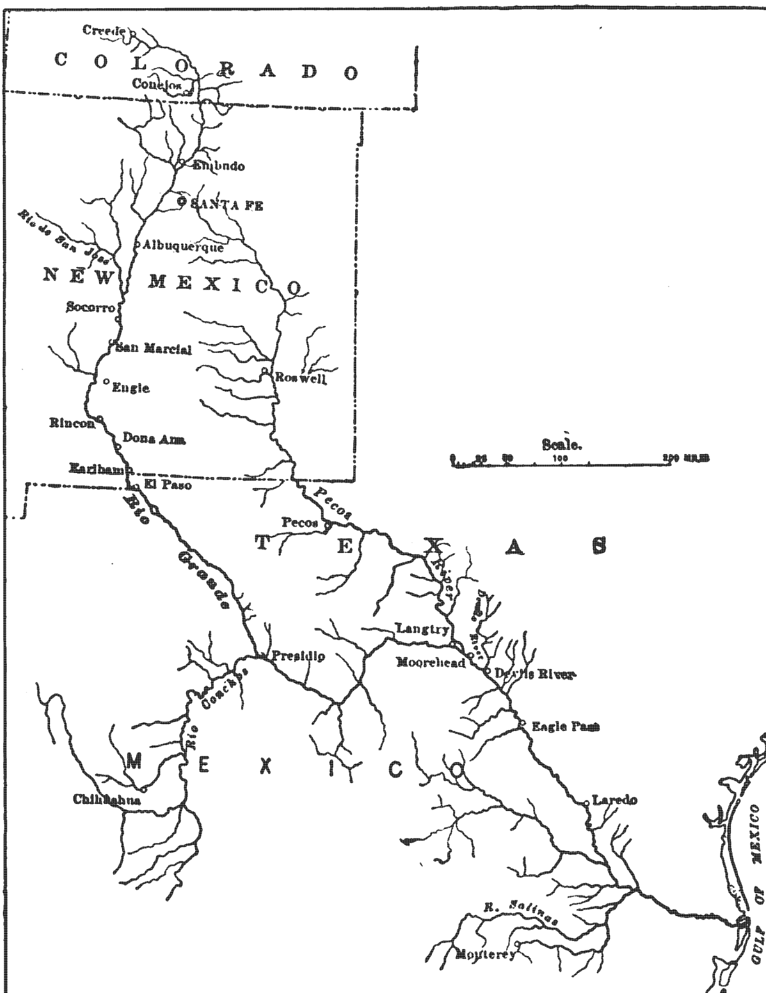


FIG. 7.—Map of Rio Grande drainage basin.

the flood down the stream can be seen from the record at San Marcial, El Paso, and Upper Presidio, [a] given in the following table:

[a] Data furnished by W. W. Follett, consulting engineer.

Flood flow of Rio Grande during part of May and June, 1905.

Date.	Cenicero (gage height).	Rio Grande (gage height).	San Marcial (discharge).	El Paso (discharge).	Upper Presidio (discharge).
	Feet.	*Feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*
May 19	5.9	11.1	15,380	6,020	....
May 20	6.6	11.6	16,550	6,180	....
May 21	7.0	11.5	17,350	6,980	....
May 22	7.2	11.4	23,400	8,360	....
May 23	7.7	11.5	28,600	9,720	....
May 24	7.95	11.8	29,070	9,800	....
May 25	8.0	11.8	23,540	10,210	4,800
May 26	8.4	11.5	28,000	12,640	4,900
May 27	8.15	11.2	27,100	14,720	5,050
May 28	8.0	10.9	25,580	16,450	5,200
May 29	7.7	10.6	23,600	17,860	5,200
May 30	7.1	10.5	20,430	18,920	5,400
May 31	6.7	9.4	19,060	18,920	5,650
June 1	6.25	9.3	19,360	20,270	5,850
June 2	6.5	9.1	19,660	20,720	6,200
June 3	7.05	9.2	19,970	20,320	6,500
June 4	7.85	9.5	17,110	18,840	6,900
June 5	8.25	10.2	16,350	17,620	7,480
June 6	8.75	10.5	16,480	15,630	8,860
June 7	8.85	10.45	15,810	14,190	9,640
June 8	9.05	10.7	15,440	14,190	10,620
June 9	8.85	11.1	15,070	17,410	11,200
June 10	8.6	10.4	15,930	18,300	11,780
June 11	8.45	10.05	17,390	20,190	12,360
June 12	8.1	9.65	18,460	23,680	12,540
June 13	7.6	9.4	16,370	23,050	13,700
June 14	6.8	9.05	13,570	23,620	13,700
June 15	6.7	8.45	12,170	23,270	12,600
June 16	6.4	8.15	11,880	23,270	12,400
June 17	6.3	7.7	12,800	20,100	12,600
June 18	6.05	7.5	13,730	17,250	11,400
June 19	5.8	7.15	10,950	13,620	12,300
June 20	5.15	6.85	10,170	9,970	12,100
June 21	4.9	6.45	8,810	7,310	11,900
Total flow, in acre-feet	....	....	1,276,000	1,070,000	513,400

There were evidently two flood waves, one reaching a maximum rate of 29,070 second-feet at San Marcial on May 24, the other reaching a maximum of 18,460 second-feet at San Marcial on June 12, nineteen days later. These two waves reached El Paso on June 2 and 14, the second having there a larger rate of flow than the first. The first wave was lost before reaching Presidio, and the maximum rate of the second one at that place was reduced to 13,700 second-feet. The total volume of flow from May 19 to June 21 at San Marcial is 1,276,000 acre-feet. The total volume at El Paso May 19 to June 21 is 1,070,000 acre-feet, and the total volume at Presidio May 25 to June 21 is 513,400 acre-feet.

COMPARISON WITH FLOOD OF OCTOBER, 1904.

The following table gives the daily rate of flow at San Marcial and El Paso for the ten days of the flood of 1904 between October 8–17, and for ten days of the flood of May, 1905. The former, a fall flood due to rain, had a much more rapid rate of rise and fall and a greater maximum rate of flow than the latter, which was a spring flood, due to melting snow. The greatest daily discharge each year from 1895 to 1905 is given on page 83.

Comparison of daily discharge of Rio Grande at San Marcial and El Paso during the floods of 1904–1905.

Date.	1904. San Marcial.	1904. El Paso.	Date.	1905. San Marcial.	1905. El Paso.
	Sec.-feet.	Sec.-feet.		Sec.-feet.	Sec.-feet.
October 8	2,880	5,740	May 21	17,350	6,980
October 9	12,000	7,670	May 22	23,400	8,360
October 10	24,000	11,370	May 23	28,600	9,720
October 11	33,000	10,550	May 24	29,070	9,800
October 12	24,800	12,010	May 25	23,540	10,210
October 13	21,750	13,800	May 26	28,000	12,640
October 14	15,900	16,200	May 27	27,100	14,720
October 15	11,100	17,100	May 28	25,580	16,450
October 16	6,250	9,300	May 29	23,600	17,860
October 17	1,550	6,300	May 30	20,430	18,920

DAMAGE.

The damage done by this flood consisted chiefly in the destruction of crops on lands overflowed and the destruction of clay or adobe buildings. The village of Tome, 35 miles south of Albuquerque, N. Mex., one of the oldest in the Territory, was reported to have been almost completely destroyed. The river broke through the dike at this place, flooded the village, softened the walls of the buildings, and caused them to fall. Some of the land along the river was injured by having the soil washed from it, while other land was enriched by the deposition of rich sediment upon it.

EFFECT OF PROPOSED ENGLE DAM ON FLOODS.

A reservoir, to be formed by a dam on the Rio Grande, will be located near Engle, N. Mex., 125 miles above El Paso. It will have a depth of 175 feet at lower end, a length of 40 miles, and a capacity of 2,000,000 acre-feet. The following table gives run-off, in acre-feet, at San Marcial each month from October, 1904, to September 30, 1905, and the total volume for these twelve months.

Estimated monthly discharge of Rio Grande near San Marcial, N. Mex., October 1, 1904, to September 30, 1905.

Month.	Maximum.	Minimum.	Mean.	Total in acre-feet.
1904.	Sec.-feet.	Sec.-feet.	Sec.-feet.	
October	33,000	1,120	7,534	463,200
November	1,430	650	870	51,770
December	1,130	355	679	41,750
1905.				
January	1,005	370	636	39,110
February	3,220	290	1,150	63,870
March	5,620	2,200	3,544	217,900
April	14,160	1,730	4,695	279,400
May	29,070	7,500	15,650	962,200
June	19,970	2,640	12,000	714,300
July	2,770	65	582	35,780
August	710	0	327	20,090
September	470	0	89	5,276
Acre-feet for period				2,895,000

It is seen that the total flow for these twelve months at San Marcial was about 1.45 times the capacity of this reservoir.

SPRING FLOODS IN COLORADO RIVER BASIN.

INTRODUCTION.

In the Colorado River drainage basin, especially its southern portion, a remarkable flood or succession of floods occurred during the period January-April, 1905. The rate of flow of some of the tributaries may have been greater, for a short time, at some previous date than during this period, but the total run-off of the Gila and Colorado during this flood was unprecedented. The flood of 1903 on the Colorado was regarded as one of the largest up to that time, but the total run-off at Yuma from January to July, 1905, was 1.8 times greater than during the corresponding period of 1903. The Gila River at Dome, near its mouth, had a total run-off of 31,000 acre-feet from January to May, 1903, inclusive, and 2,957,800 acre-feet for the same period of 1905.

The Colorado River proper is formed by the junction of the Green and Grand rivers in the southern part of Utah, flows in a general southwesterly direction for nearly 1,000 miles, and empties into the Gulf of California. The principal tributaries are the Gila, Little Colorado, San Juan, Virgin, and Williams. The following table, prepared mainly from data in Water-Supply and Irrigation Paper No. 44 (p. 82), gives the distance from the mouth to places along the river, their height above sea level, and the fall per mile between them.

Distances and altitudes along Colorado River, and fall per mile.

Locality.	Distance from mouth.	Height above sea.	Fall per mile.
	Miles.	*Feet.*	*Feet.*
Mouth	0	0	0
Yuma (mouth of Gila River)	150	125	0.8
Ehrenberg	261	....	....
Mouth of Williams River	340	375	1.3
Needles Bridge	367	....	....
Needles	385	448	1.6
Mohave City	440	....	....
Hardyville	447	....	....
Bullshead	454	....	....
Mouth of Virgin River	555	935	2.9
Mouth of Grand Wash (fault)	600	1,000	1.4
Mouth of Diamond Creek	650	1,312	6.2
Toroweap Valley (fault)	700	1,625	6.3
Mouth of Kanab Creek	730	1,810	6.2
	790	2,300	8.2
	800	2,520	22.0
Mouth of Little Colorado River	815	2,625	7.0
Mouth of Paria River	880	3,187	8.6
Mouth of Navajo Creek	905	3,220	1.3
Crossing of the Fathers	920	3,250	2.0
Mouth of San Juan River	957	3,310	1.6
Mouth of Escalante River	970	3,325	1.2
Mouth of Dirty Devil River	1,030	3,434	1.8
	1,067	3,750	31.2
Mouth of Grand River	1,080	3,775	1.9

The Colorado River drainage basin, including the Green and Grand rivers, extends from 43.5° to 31° north latitude, and from 115.5° to 106° west longitude, and comprises an area

of about 225,000 square miles. Within this basin is found some of the most varied topography on this continent. The canyon of the Colorado has a depth of 3,000 to 6,000 feet below the surrounding plateaus. The greater part of the basin consists of elevated plateaus bordered with cliffs. The slopes are steep and nearly impervious, hence the run-off is very rapid.

PRECIPITATION.

The mean annual precipitation varies from less than 5 inches in the southwestern part of the basin to more than 15 inches on some of the high plateaus and mountains. On the headwaters of the Duchesne River the precipitation must be more than 20 inches, as the measured annual run-off is 14.5 inches.

The following table, prepared from the records of the United States Weather Bureau gives the monthly precipitation from January to April, 1905, at places in the Gila River basin and vicinity. It also gives the mean monthly precipitation at some of these places for comparison:

Monthly precipitation in the Gila and Little Colorado River basins from January 1 to April 30, 1905, compared with the mean monthly precipitation of same localities.

Place.	January.		February.		March.		April.		Total.	
	1905.	Mean.	1905.	Mean.	1905.	Mean.	1905.	Mean.	1905.	Mean.
Jerome, Ariz	5.10	1.44	7.80	2.35	7.30	1.35	3.70	1.07	23.90	6.21
Prescott, Ariz	4.74	1.55	7.92	1.76	6.17	1.78	3.81	0.81	22.64	5.90
Seligman, Ariz	1.97	....	3.27	....	2.16	....	1.65	....	9.05	....
Alma, N. Mex	1.44	0.99	6.05	0.39	5.35	0.56	2.40	0.38	15.24	2.32
Young, Ariz	5.21	....	7.94	....	7.50	....	4.59	....	25.24	....
Alpine, Ariz	3.15	....	5.88	....	4.91	....	3.20	....	17.14	....
Fort Apache, Ariz	3.45	1.36	4.31	1.80	6.79	1.63	5.00	0.71	19.55	5.50
Fort Grant, Ariz	0.36	0.99	2.34	1.13	0.99	0.71	1.21	0.32	4.90	3.15
Phoenix, Ariz	3.31	0.80	4.64	0.70	2.38	0.58	2.59	0.44	12.92	2.52
Oro, Ariz	3.61	1.03	6.22	1.21	6.07	0.98	2.35	0.41	18.25	3.63
Deming, N. Mex	1.53	0.43	2.08	0.31	2.15	0.42	1.87	0.06	7.63	1.22
Fort Bayard, N. Mex	3.07	0.66	4.26	0.86	4.33	0.58	2.93	0.24	14.59	2.34
San Carlos, Ariz	3.46	1.33	5.03	1.44	3.30	0.98	3.34	0.42	15.13	4.17
Cambray, N. Mex	1.69	0.22	2.01	0.60	1.02	0.23	0.55	0.02	5.27	1.07
Bowie, Ariz	1.91	1.63	3.29	1.15	2.65	0.92	1.19	0.21	9.04	3.91
Gage, N. Mex	....	....	3.00	0.37	2.95	0.37	1.78	0.03	7.73	....
Dudleyville, Ariz	3.57	1.35	5.88	1.39	3.75	1.02	3.90	0.54	17.10	4.30
Lordsburg, N. Mex	1.57	0.53	3.35	0.32	3.24	0.44	1.27	0.09	9.43	1.38
Mesa, Ariz	2.85	1.27	4.86	0.94	3.42	0.76	2.70	0.45	13.83	3.42
Luna, N. Mex	2.09	....	3.53	....	2.47	....	2.37	....	10.46	....
Buckeye, Ariz	2.91	1.08	6.46	0.80	3.61	0.72	2.04	0.22	15.02	2.82
Maricopa, Ariz	1.60	0.74	2.70	0.70	1.72	0.45	1.71	0.14	7.73	2.03
Yuma, Ariz	1.15	0.42	3.43	0.51	3.33	0.26	0.16	0.08	8.07	1.27
Bisbee, Ariz	1.12	....	5.71	....	5.26	....	4.04	....	16.13	....
Benson, Ariz	1.08	....	3.34	....	4.20	....	2.01	....	10.63	....
Duncan, Ariz	2.10	....	3.72	....	3.36	....	1.74	....	11.92	....
Holbrook, Ariz	1.29	....	2.98	....	2.93	....	1.57	....	8.77	....
Kingman, Ariz	1.77	....	4.47	....	3.05	....	2.42	....	11.71	....
Fort Wingate, N. Mex	2.30	....	2.31	....	2.85	....	4.05	....	11.51	....
Flagstaff, Ariz	3.20	....	5.79	....	4.02	....	2.65	....	15.66	....
Tuba, Ariz	1.45	....	1.21	....	0.96	....	2.58	....	6.20	....

It is seen that the precipitation for this period at all of these places was several times greater than the normal. At some places where the rainfall per month is generally about one-half inch it was from 5 to 7 inches per month. Excessive precipitation for a short

time over comparatively small areas is not uncommon, but such long periods of excessive rainfall over so large an area in this section is very remarkable. In a considerable part of the Salt and Verde River basins the precipitation during these four months was over 20 inches.

TRIBUTARIES OF COLORADO RIVER ABOVE HARDYVILLE.

The subjoined table shows the discharge of tributaries of the Colorado during the floods of June, 1905:

Daily rate of flow of Colorado, Green, Grand, Gunnison, and San Juan rivers, during floods of June, 1905.

[Drainage areas above gaging stations in square miles: Green River, 38,200; Grand River, 8,546; Gunnison River, 7,863.]

Day.	Colorado River at Hardyville, Ariz.		Green River at Greenriver, Utah.		Grand River at Palisade, Colo.		Gunnison River at Whitewater, Colo.		San Juan River at Farmington, N. Mex.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1					19.35	25,040	11.65	17,780	10.05	15,650
2					20.05	29,200	12.45	21,280	10.7	17,600
3					20.35	31,000	12.75	22,710	12.4	22,700
4					21.0	35,000	13.15	24,660	12.25	22,250
5	10.8	64,310	9.6	29,260	22.05	41,620	13.85	28,080	12.35	22,550
6	11.85	73,890	9.8	30,970	22.0	41,300	13.6	26,860	13.10	24,800
7	12.5	80,070	9.85	31,400	21.8	40,020	13.05	24,160	11.65	20,450
8	13.1	85,880	10.05	33,160	21.35	37,180	13.2	24,900	11.8	20,900
9	13.7	91,760	10.3	35,400	22.0	41,300	13.5	26,370	12.0	21,500
10	14.4	98,620	10.55	37,700	22.0	41,300	13.55	26,620	11.9	21,200
11	14.3	96,500	10.5	37,230	21.3	36,860	12.95	23,680	12.0	21,500
12	14.0	93,500	10.05	33,160	21.25	36,850	12.5	21,520	12.05	21,650
13	14.3	94,000	10.2	34,500	20.6	32,530	12.25	20,360	11.9	21,200
14	14.45	94,500	10.2	34,500	20.35	31,000	12.05	19,460	11.6	20,300
15	14.5	93,500	9.95	32,280	20.4	31,310	11.85	18,600	11.4	19,700
16	13.8	85,500	9.85	31,400	20.4	31,310	11.7	17,980	11.4	19,700
17	13.3	79,000	9.35	27,180	19.9	28,300	11.1	15,680	11.75	20,750
18	12.8	73,000	9.25	26,370	19.45	25,620	10.45	13,420	10.6	17,300
19	12.5	70,500	9.15	25,580	19.05	23,290	10.15	12,440	10.7	17,600
20	12.2	67,500	9.05	24,790	18.7	21,300	9.9	11,650	10.75	17,750

GREEN RIVER AT GREENRIVER, UTAH.

The daily rate of flow of Green River, the largest of the two streams that form the Colorado, at the gaging station near Greenriver, is given on page 40. The station is located about 70 miles above the mouth of the river and the drainage area above this point is 38,200 square miles.

The stage increased gradually from 9.6 feet on June 5 to 10.55 feet on June 10, and the rate of flow increased from 29,260 second-feet to 37,700 second-feet. From the 11th to the 20th the rate of flow gradually decreased from 37,230 second-feet to 24,790 second-feet. The greatest daily rate of flow was about 1 second-foot per square mile. In May, 1897, the rate of flow was 68,800 second-feet, and in June, 1899, it was 58,350 second-feet.

GRAND RIVER AT PALISADE, COLO.

The daily rate of flow of Grand River, which unites with the Green to form the Colorado at the gaging station at Palisade, Colo., is given on page 40. Between June 2 and June 16 the stage varied from 20 to 22 feet and the rate of flow from 29,000 to 41,300 second-feet.

The greatest daily rate during this period was 4.83 second-feet per square mile. This station was established in 1902. The greatest rate of flow during these four years prior to June, 1905, was 24,800 second-feet in May, 1904.

GUNNISON RIVER AT WHITEWATER, COLO.

The daily rate of flow of Gunnison River during this flood at the gaging station, 10 miles above its mouth, is given on page 40. From June 1 to June 16 the stage varied from about 11.7 to 13.85 feet and the rate of flow from 17,780 to 28,080 second-feet. The maximum daily rate during this time was 3.67 second-feet per square mile. This station has been in operation four years. The greatest daily rate during this period prior to June, 1905, was 17,810 second-feet in June, 1903.

SAN JUAN RIVER NEAR FARMINGTON, N. MEX.

The San Juan is the largest tributary of the upper Colorado, which it enters from the east about 120 miles below the junction of the Green and the Grand, and about 15 miles north of the Utah-Arizona boundary line. The daily rate of flow at the gaging station near Farmington, N. Mex., is given on page 40. From June 1 to June 21, the stage varied from about 10 to 13.1 feet, and the rate of flow from 15,600 to 24,800 second-feet. The greatest daily rate in 1904 was 20,000 second-feet in October.

LITTLE COLORADO RIVER.

The excessive precipitation in the basin of the Little Colorado during the months January-April, noted on page 39, resulted in great floods that swept away several large dams and deprived many thousand acres of irrigated land of water.

A gaging station was established on this stream at Holbrook, Ariz., March 17, after the largest flood that destroyed the dams had passed. The records at this place show that during the period, March 17 to April 30, the discharge varied from 1,000 to 2,075 second-feet.

The maximum stage, due to failure of the St. Johns dam, was 11.5 feet. This stage is about 3 feet higher than that on November 29, when the discharge was estimated to have been about 20,000 second-feet.

COLORADO RIVER AT HARDYVILLE, ARIZ.

A gaging station is located on Colorado River about one-fourth of a mile above the deserted town of Hardyville, 7 miles above Fort Mohave and 297 miles above Yuma. Discharge measurements are made from a car on a cable, and fluctuations of stage are read daily on a rod fastened to the left bank near the cable.

The daily gage height and rate of flow from June 5 to June 20, during this flood, are given on page 40.

At this station there was a gradual increase from a stage of 10.8 feet and a discharge of 64,310 second-feet, on June 5, to a stage of 14.4 feet and a discharge of 98,620 second-feet on June 10. From June 10 to June 15 the stage varied from 14 to 14.5 feet. On the 20th it had fallen to 12.2 feet.

GILA RIVER BASIN.

INTRODUCTION.

Gila River rises in the mountainous country of southwestern New Mexico, flows in a general southwesterly direction through Arizona, and empties into Colorado River 1 mile above Yuma, Ariz. Its principal tributaries are the Salt, Verde, San Francisco, Agua Fria, and Hassayampa from the north and the San Pedro and Santa Cruz from the south. The location of these streams is shown on Pl. II.

The total area drained by this river is 71,140 square miles, 40 per cent of which has an elevation of less than 3,000 feet and is largely agricultural land if supplied with water. About

27 per cent has an elevation of more than 5,000 feet and from this part comes the water supply. This high plateau, which lies at the headwaters of the Gila, in the eastern and northeastern part of the drainage basin, intercepts the moisture-laden winds from the southwest and causes them to precipitate their moisture. The run-off from the remaining 73 per cent is small, except during an occasional period of heavy storms like that of the winter and spring of 1905. The run-off is rapid, the slopes being steep and impervious and the fluctuations in flow are very great, as can be seen from fig. 8.

PRECIPITATION.

The precipitation in this basin during the floods of 1905 can be seen from the precipitation records on page 39. Large parts of the Salt, Verde, and Gila basins are in the area of greatest precipitation, and more than 20 inches of rain fell on them during these four months.

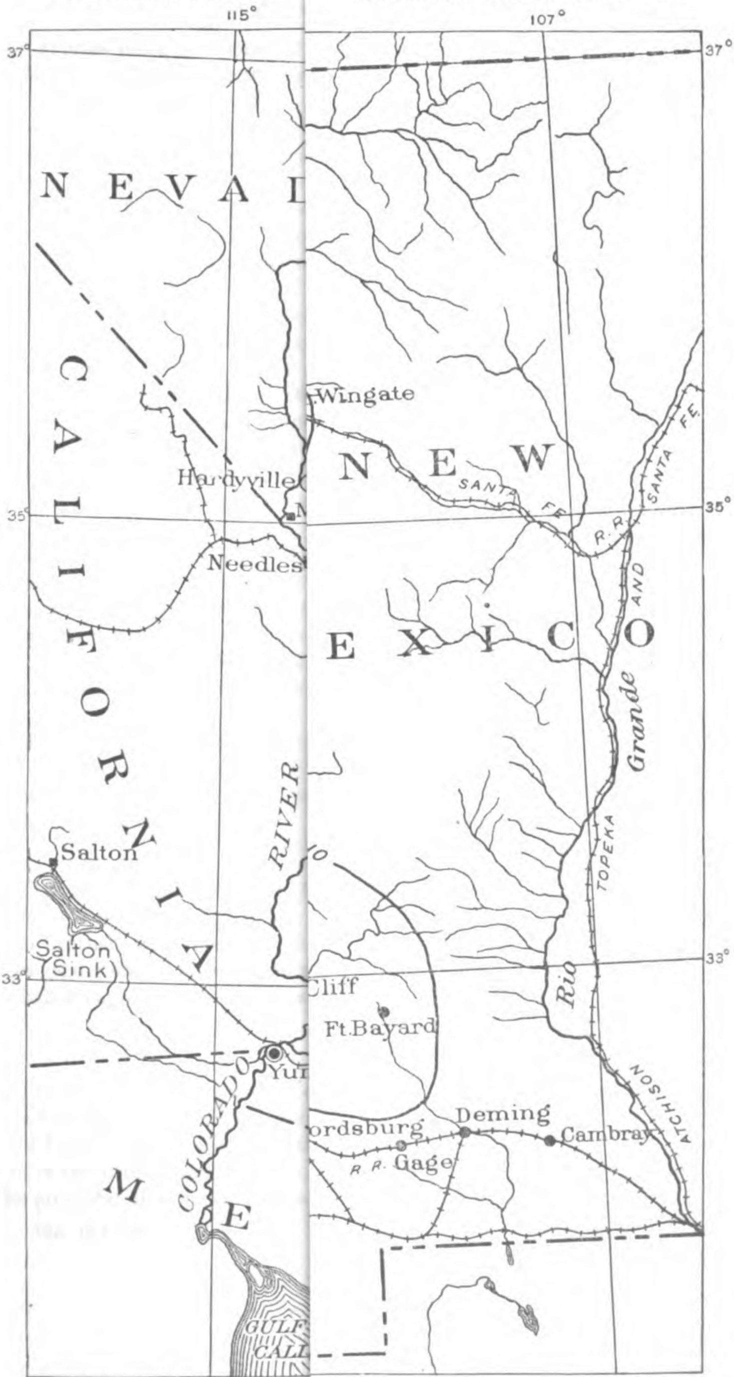
SAN FRANCISCO RIVER.

The San Francisco is an important tributary of the Gila, which it enters from the north about 30 miles above Solomonsville, Ariz. The gaging station on it is located at Alma, N. Mex. The basin above the station is mountainous and comprises an area of about 18,000 square miles. The following table gives the daily rate of flow at this station during these floods:

Daily discharge, in second-feet, of San Francisco River at Alma, N. Mex., in 1905.

[Drainage area, 1,800 square miles.]

Date.	Discharge.	Date.	Discharge.	Date.	Discharge.
January 9	80	March 7	910	April 4	1,380
January 10	3,162	March 8	2,120	April 5	1,932
January 11	1,080	March 9	325	April 6	1,874
January 12	357	March 16	230	April 7	1,758
February 3	287	March 17	3,092	April 8	1,590
February 4	910	March 18	2,164	April 9	1,245
February 5	910	March 19	1,700	April 10	1,245
February 6	1,310	March 20	2,280	April 11	1,200
February 7	560	March 21	1,590	April 12	1,430
February 8	370	March 22	1,480	April 13	1,990
February 16	200	March 23	1,480	April 14	1,400
February 17	4,760	March 24	1,290	April 15	1,200
February 18	5,060	March 25	1,110	April 16	975
February 19	180	March 26	1,110	April 22	618
February 27	340	March 27	1,020	April 23	1,535
February 28	4,010	March 28	885	April 24	1,700
March 1	3,410	March 29	800	April 25	1,380
March 2	2,360	March 30	602	April 26	1,020
March 3	2,510	March 31	642	April 27	930
March 4	2,510	April 1	681	April 28	1,020
March 5	2,660	April 2	1,155	April 29	760
March 6	460	April 3	2,048	April 30	602


115°
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NEVAD
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NEW MEXICO
Wingate
Hardyville
Needles
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TOPEKA
ATCHISON
RIVER
COLORADO
Salton
Salton Sink
Cliff
Ft.Bayard
Yu
ordsburg
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GILA RIVER NEAR SOLOMONSVILLE, ARIZ.

For 20 miles below the mouth of the San Francisco the Gila flows in a canyon. About 10 miles above Solomonsville the topography changes, and from this place to a point 6 miles below San Carlos—nearly 70 miles—the river flows in a fertile valley where irrigation ditches take water from it on both sides. This is one of the finest irrigated portions of Arizona.

Great damage was done in this valley by the floods of 1905. The banks of the river are composed of sandy loam which is easily eroded, and several hundred acres of land were washed away. The stream bed was doubled or trebled in width by these floods and is now strewn with uprooted trees that before the flood grew along the banks. On some areas that were protected from the direct scouring action of the current material has been deposited to depths ranging from 6 inches to 4 feet, destroying the land for agricultural purposes. The irrigation works, especially the ditches, were badly damaged, many orchards and fields of alfalfa were destroyed or badly injured, the railway bridge at San Carlos was washed away in January, the railway along the river was damaged several times at many places, and traffic was interrupted for the greater part of the time from January 10 to April 15.

During the flood of January 11 the Gila rose very rapidly in the vicinity of Solomonsville and overflowed all the land below the level of the Montezuma canal. It overflowed the river bank above the heads of this canal, flowed through the city, and before the canal could be cut to allow the water to pass back into the river many adobe houses were destroyed.

The gage at the gaging station at San Carlos was washed away on January 10 at a river stage of 5½ feet above ordinary water. A new gage was put in February 1 and during February the stage varied from 1.8 feet to 9 feet. This gage was washed away March 17 at a stage of 8 feet. The bed of the stream was changed so much during these floods that reasonably accurate estimates of the daily rate of flow at this place can not be given.

The daily rate of flow from June 27 to July 14 varied from 4 to 6 second-feet. The maximum rate of flow during these floods was 5,060 second-feet, or 2.8 second-feet per square mile.

A large amount of damage was done by these floods in the vicinity of Clifton, Ariz. The steel railway bridge across the river was swept away, the roadbed was damaged, and traffic interrupted for several days, a few small buildings were swept away, and the smelters along the river were damaged.

SAN PEDRO RIVER.

The San Pedro enters the Gila from the south at Dudleyville, Ariz. The total area drained by it is 3,456 square miles. The greatest rate of flow in January was 124 second-feet, in February 235 second-feet, in March 668 second-feet, and in April 145 second-feet. As this gaging station is about 110 miles above the mouth of the river, these figures afford little indication of the rate of flow at the mouth.

SALT RIVER.

Salt River is the largest tributary of the Gila, which it enters from the north 14 miles west of Phoenix, Ariz. Its principal tributaries are the Verde, entering from the north at McDowell, and Tonto Creek, entering from the north at Roosevelt. The basin of the Salt above the mouth of the Verde is mountainous, with deep canyons and very steep slopes.

The precipitation at places in this basin during January-April is given on page 39.

The daily rate of flow during the floods of these four months as measured at the gaging station at Roosevelt, Ariz., is given in the following table:

Daily discharge, in second-feet, of Salt River at Roosevelt, Ariz., during floods of January–April, 1905.

Date.	Discharge.	Date.	Discharge.	Date.	Discharge.
January 9	346	March 1	17,100	March 28	6,740
January 10	5,900	March 2	12,150	March 29	6,000
January 11	12,300	March 3	9,250	March 30	6,700
January 12	9,460	March 4	8,925	March 31	7,300
Januray 13	4,000	March 5	11,300	April 1	7,548
January 14	2,400	March 6	11,330	April 2	8,076
January 15	1,685	March 7	11,220	April 3	9,819
January 16	1,513	March 8	11,060	April 4	12,020
January 17	1,341	March 9	11,220	April 5	8,937
January 18	1,170	March 10	11,540	April 10	8,937
January 19	999	March 11	11,500	April 11	20,040
February 2	625	March 12	8,200	April 12	43,350
February 3	3,900	March 13	22,050	April 13	45,470
February 4	31,400	March 14	38,700	April 14	20,370
February 5	18,800	March 15	17,600	April 15	14,010
February 6	16,700	March 16	12,150	April 16	10,620
February 7	8,250	March 17	39,800	April 17	8,864
February 8	4,500	March 18	36,550	April 23	8,777
February 9	3,145	March 19	23,200	April 24	11,500
February 15	2,867	March 20	44,400	April 25	12,750
February 16	4,040	March 21	23,440	April 26	12,500
February 17	21,550	March 22	11,940	April, 27	11,160
February 18	20,450	March 23	9,524	April 28	10,800
February 19	7,000	March 24	9,895	April 29	9,906
February 20	4,800	March 25	8,040	April 30	9,370
February 27	4,400	March 26	7,860		
February 28	27,550	March 27	7,480		

NOTE.—The daily discharge during May varied gradually from 9,350 to 1,950 second-feet.

The table shows one flood in January, three in February, four in March, and three in April. The largest of these floods occurred April 13. The rate of flow was 45,470 second-feet, or 7.9 second-feet per square mile; on March 20 the daily rate was 44,400 second-feet, nearly as large as on April 13. The highest stage during these four months at this station was 23.5 feet and the lowest 6.9 feet.

The following table gives the greatest daily rate of flow of Salt River at Roosevelt each year, from 1889 to 1905:

Maximum daily discharge, in second-feet, of Salt River at Roosevelt, Ariz., 1889–1905.[a]

[Drainage area, 5,756 square miles.]

Year.	Month.	Discharge.	Year.	Month.	Discharge.
1889....	March........................	18,930	1900...	November....................	2,220
1890....	February.....................	71,640	1901...	February.....................	4,170
1891....	February.....................	150,000	1902...	August.......................	4,680
1892....	October......................	770	1903...	April..........................	2,050
1894....	March........................	1,430	1904...	August.......................	14,700
1895....	January......................	46,810	1905...	January......................	12,300
1896....	July...........................	5,530	1905...	February.....................	27,550
1897....	January......................	10,420	1905...	March........................	44,400
1898....	August.......................	1,210	1905...	April..........................	45,470
1899....	August.......................	3,330	1905...	November....................	97,710

[a] This station is described in Water-Supply Paper No. 100, p. 42.

According to these records, the greatest daily rate of flow during these seventeen years was nearly 26 second-feet per square mile in February, 1891.

The following table gives the maximum, minimum, and mean monthly run-off of the Salt and Verde rivers for January–April, 1905, and for the same months of 1891:

Comparison of floods of 1891 [a] *and 1905* [b] *on Salt River at Roosevelt and on Verde River at McDowell, Ariz.*

SALT RIVER AT ROOSEVELT.

[Measurements in second-feet.]

Date.	Maximum.		Minimum.		Mean.	
	1891.	1905.	1891.	1905.	1891.	1905.
January..................................	8,900	12,300	551	165	1,777	1,611
February................................	150,000	27,550	413	526	19,408	8,207
March....................................	4,970	44,400	753	6,000	2,768	15,300
April......................................	2,180	45,470	1,654	6,495	1,922	12,550
Mean, January-April..............	....	....	....	....	6,467	9,417
Acre-feet, January-April.........	....	....	....	....	1,471,000	2,242,000

VERDE RIVER AT McDOWELL.

Date.	Maximum.		Minimum.		Mean.	
	1891.	1905.	1891.	1905.	1891.	1905.
January..................................	7,190	10,060	445	241	1,435	1,419
February................................	135,000	32,970	371	499	17,467	7,709
March....................................	3,460	29,410	525	1,887	1,928	8,780
April......................................	606	32,140	459	1,411	534	5,227
Mean, January-April..............	....	....	....	....	5,341	5,784
Acre-feet, January-April.........	....	....	....	....	1,209,000	1,366,000

[a] Prepared from data Water Supply and Irrigation Paper No. 73, pp. 14 and 26.
[b] Discharge obtained by taking proportional part of discharge of Salt River at Arizona dam.

The maximum daily rate of flow of both Salt and Verde rivers was more than three times as great in February, 1891, as at any time during the period January–April, 1905, but the total flow of Salt River below the mouth of the Verde was 1.24 times greater during the period January–April, 1905, than during the same period of 1891.

VERDE RIVER.

The precipitation in the drainage basin of the Verde during the months January–April can be seen from the table on page 39. The daily rate of flow during these floods, as

measured at the gaging station at McDowell, near the mouth of the river, is given in the following table:

Daily discharge, in second-feet, of Verde River at McDowell, Ariz., during floods, January to April, 1905.

Date.	Discharge.	Date.	Discharge.	Date.	Discharge.
January 9	285	February 22	4,311	March 20	10,630
January 10	8,674	February 23	5,610	March 21	9,368
January 11	10,060	February 24	12,170	March 22	8,110
January 12	7,394	February 25	6,126	March 23	6,853
January 13	2,379	February 26	4,572	March 24	5,594
January 14	1,400	February 27	4,650	March 25	5,070
January 15	1,100	February 28	21,050	March 26	4,755
January 16	860	March 1	25,130	March 27	3,916
January 17	755	March 2	10,580	March 28	3,077
January 18	1,100	March 3	8,800	March 29	2,770
January 19	944	March 4	8,107	March 30	2,158
February 2	507	March 5	7,414	March 31	1,887
February 3	968	March 6	5,928	April 10	1,493
February 4	32,970	March 7	5,276	April 11	6,433
February 5	32,970	March 8	4,884	April 12	32,140
February 6	19,310	March 9	3,946	April 13	24,640
February 7	9,743	March 10	3,289	April 14	15,160
February 8	5,400	March 11	2,617	April 15	13,720
February 9	3,750	March 12	2,539	April 16	10,710
February 15	1,403	March 13	7,612	April 17	7,566
February 16	1,367	March 14	25,500	April 18	5,471
February 17	4,950	March 15	10,580	April 19	3,639
February 18	9,767	March 16	10,780	April 20	2,337
February 19	8,641	March 17	29,410	April 21	1,893
February 20	6,130	March 18	23,460	April 22	1,617
February 21	5,004	March 19	12,120		

The greatest daily rate of flow during these four months at this place was about 33,000 second-feet, on February 4 and 5. The greatest daily rate per square mile during this period was 5.5 second-feet, and the stage varied from 1 foot to 13.25 feet.

The monthly and total run-off at this station for these four months were given on page 45.

The following table gives the greatest daily rate of flow of the Verde River near its mouth each year from 1889-1905:

Maximum daily discharge, in second-feet, of Verde River at McDowell, Ariz., 1889-1905.[a]

[Drainage area, 6,000 square miles.]

Year.	Month.	Discharge.	Year.	Month.	Discharge.
1889	March	13,180	1899	October	3,770
1890	February	64,480	1900	November	2,470
1891	February	135,000	1901	February	6,610
1894	March	996	1903	April	[b] 95,000
1895	January	33,000	1904	July	6,080
1896	August	5,320	1905	February	32,970
1897	January	15,690	1905	April	32,140
1898	July	1,890	1905	November	61,460

[a] This station is described in Water-Supply Paper No. 100, p. 31.
[b] Gage height, 19 feet. Discharge, upward of 95,000 second-feet.

According to these records the greatest daily rate of flow at this station during these seventeen years was about 23 second-feet per square mile in February, 1891.

GILA RIVER AT DOME, ARIZ.

The following table gives the daily discharge of the Gila at Dome (Gila City), Ariz., 15 miles from the mouth of the river, for January-May, 1905:

Daily discharge, in second-feet, of Gila River at Dome, Ariz., for period January-May, 1905.

Day.	January.	February.	March.	April.	May.
1	0	80	5,150	6,800	9,500
2	0	0	21,500	6,800	8,100
3	0	0	34,000	6,000	8,500
4	0	0	11,800	7,300	7,700
5	0	280	5,000	8,500	6,000
6	0	2,200	3,050	12,400	6,400
7	0	20,800	1,050	13,800	6,000
8	0	82,000	450	9,000	5,000
9	0	35,800	370	8,100	5,000
10	40	14,900	300	8,500	5,000
11	2,220	6,900	5,000	9,000	4,100
12	2,600	2,920	10,000	8,500	5,600
13	2,840	60	3,800	22,000	5,000
14	2,960	1,920	3,500	64,000	4,400
15	4,680	300	10,300	34,000	4,700
16	18,600	0	39,000	23,000	5,000
17	26,000	140	20,000	15,300	5,000
18	10,200	230	27,800	10,900	4,700
19	5,650	24,800	62,000	8,300	3,800
20	3,690	42,800	95,000	6,200	4,400
21	3,060	45,200	25,500	5,150	3,800
22	2,560	40,200	20,000	6,400	4,100
23	1,990	630	18,000	8,300	4,400
24	1,660	300	16,100	7,900	3,800
25	1,460	900	14,500	9,250	3,500
26	1,290	9,250	13,100	12,750	3,500
27	1,180	5,150	11,800	12,100	3,500
28	1,020	5,300	10,600	13,100	3,300
29	830	....	9,500	12,750	2,800
30	560	....	8,500	11,200	2,350
31	310	....	7,700	....	2,150
Total	95,400	343,080	514,370	387,300	151,100
Mean	3,077	12,250	16,590	12,910	4,874
Run-off, in acre-feet	189,200	680,300	1,020,000	768,200	299,700

The table shows one flood in January, two in February, two in March, and one large and two small ones in April. The greatest rate of flow was 95,000 second-feet, on March 20. The first flood in February is more characteristic of floods on this stream than any of the others. They are generally of short duration, the rise and fall being very rapid. The long-continued rains of this period gave a character to these floods not unlike that of streams in the eastern part of the country.

The total run-off for the five months is 2,957,400 acre-feet. To appreciate the magnitude of the run-off on this stream during this period it is necessary to remember that this stream is usually dry at this place about ten months of the year.

The stream at this place was about 4 feet higher during the great flood of February, 1891, than during this flood. The rate of flow of the river for a given gage height changes greatly at this station. On February 8, 1905, the rate was found to be 82,000 second-feet for a gage height of 16.95 feet; on March 20 it was found to be 95,000 second-feet for a gage height of 13.1 feet The bed is sandy and not only scours out during a flood and fills in after it, but the channel changes from one side of the bottom to the other. The width when the stream is flowing is generally not more than 100 feet, but during some of these floods the whole bottom was flooded; thousands of acres of land that were covered with arrowwood, mesquite, and cottonwood before the floods are now part of the river bed or bare mud flats. This continual changing of the river bed has made it exceedingly difficult to secure reliable estimates of the rate of flow, and some of the estimates may be largely in error.

The damage done by the floods along the lower Gila consisted mainly in washing away large areas of good land along the river, some of which was under cultivation.

SUMMARY.

The following table gives the monthly and total flow in acre-feet, January–April, 1905, at four of the gaging stations in this basin:

Monthly and total discharge, in second-feet, at stations in Gila River basin, January–April, 1905.

Stream.	Place.	January.	February.	March.	April.	Total.
San Francisco	Alma, N. Mex	17,340	43,870	79,260	72,830	213,300
Verde	McDowell, Ariz	87,250	428,100	539,900	311,000	1,366,000
Salt	Roosevelt, Ariz	99,060	455,800	940,800	746,800	2,242,000
Gila	Dome, Ariz	189,200	680,300	1,020,000	768,200	2,658,000

The flow at the Arizona dam is approximately the sum of the volumes of flow of the Salt at Roosevelt and the Verde at McDowell, which is 3,608,000 acre-feet. The total flow at this place is about 1.36 times the volume of flow for the same period at Dome, near the mouth of the Gila.

COLORADO RIVER AT YUMA, ARIZ.

The gaging station at Yuma is below the mouth of the Gila, and the records there show the combined flow of the Gila and upper Colorado. The Hardyville station is about 300 miles above Yuma. The only comparatively large stream entering between these stations is Williams River. Along the Colorado between these stations there are from 200,000 to 225,000 acres of lowlands subject to overflow during floods. Overflow of these lowlands begins at a gage height of about 24.5 feet,[a] Yuma gage. The Colorado reached a stage of 24.85 feet at Yuma (8 feet Hardyville gage) on May 23 and remained above 24.5 feet until July 5. These lowlands were therefore flooded for about forty-five days.

[a] Second Ann. Rept. U. S. Reclamation Service, p. 150.

The following table gives the daily rate of flow of the Colorado at Yuma from January 1 to July 31, 1905:

Daily discharge, in second-feet, of Colorado River at Yuma for the period January–July, 1905.

Day.	January.	February.	March.	April.	May.	June.	July.
1	3,750	5,800	29,070	20,690	41,520	61,500	57,800
2	3,750	6,054	39,260	20,100	39,700	65,300	55,500
3	3,800	6,500	70,170	19,480	39,700	68,160	50,640
4	3,985	6,632	70,200	19,450	37,280	67,900	45,000
5	4,300	9,800	51,100	21,000	37,100	67,600	44,950
6	4,570	16,560	44,310	30,100	37,410	67,600	42,400
7	4,700	9,400	44,100	29,840	38,000	69,500	40,100
8	4,500	62,080	43,100	25,800	40,050	72,930	37,200
9	4,170	82,820	36,400	24,800	46,000	70,300	35,500
10	16,090	52,580	34,400	24,900	49,200	69,600	32,980
11	6,400	37,320	38,620	23,000	52,000	71,000	32,100
12	6,300	29,700	42,000	26,100	48,000	72,590	31,720
13	6,350	22,800	38,870	45,800	38,840	76,000	30,870
14	7,000	21,900	32,000	93,800	37,800	82,020	29,500
15	8,370	22,500	36,720	97,500	37,300	82,000	27,710
16	8,600	18,610	60,640	70,100	37,320	83,000	28,300
17	20,100	14,600	65,820	45,000	37,000	86,000	31,100
18	27,500	16,490	62,400	43,600	33,910	88,500	25,300
19	19,300	31,500	73,440	45,050	34,200	94,320	22,320
20	12,120	47,000	110,800	43,400	34,580	91,500	22,250
21	9,300	54,200	103,500	39,500	35,700	92,400	22,000
22	10,170	54,730	91,200	35,900	37,000	92,400	21,500
23	7,863	32,990	76,930	33,900	38,400	89,800	20,900
24	7,900	21,990	58,600	31,690	41,500	84,800	20,800
25	7,025	18,850	43,050	33,000	43,700	82,000	20,650
26	6,770	30,500	34,600	37,160	45,300	77,610	20,460
27	6,250	27,730	31,020	41,630	47,600	73,500	19,700
28	5,730	25,000	29,500	39,000	51,100	68,500	18,910
29	5,400	....	26,900	35,000	54,810	64,370	17,200
30	5,070	....	24,390	38,700	56,300	61,500	17,500
31	4,900	....	23,500	59,020	59,020	....	16,750
Mean run-off	8,130	28,100	50,540	37,830	42,170	76,470	30,310
Per square mile	0.0361	0.125	0.225	0.168	0.187	0.340	0.135
Depth in inches	0.042	0.130	0.259	0.187	0.216	0.379	0.156
Acre-feet	499,900	1,561,000	3,108,000	2,251,000	2,593,000	4,550,000	1,864,000

There were two flood periods in January—one that reached a rate of 16,090 second-feet on the 10th and one that reached a rate of 27,500 second-feet on the 18th; two floods in February—one that reached a rate of 82,800 second-feet on the 9th and one that reached a rate of 54,730 second-feet on the 21st; two floods in March—one that reached a rate of 70,170 second-feet on the 4th and one that reached a rate of 110,800 second-feet on the 20th; one in April, that reached a rate of 97,500 second-feet; one in May, with a rate of 52,000 second-feet; and one in July, with a maximum rate of 94,300 second-feet. The flood in July came from the upper Colorado; all the others came from the Gila, as can be seen from the records at Dome and Hardyville. The daily flow at this station for this period is shown on fig. 8. The highest stage of water at the Yuma gage during these floods was 30.3 feet, on March 20, when the rate of flow was 110,800 second-feet or 0.49 second-foot

per square mile. The highest stage of water at the Yuma gage during the great flood on the Gila in 1891 was 33.2 feet. The greatest flow from the Colorado above Yuma was 92,400 second-feet, on June 21.

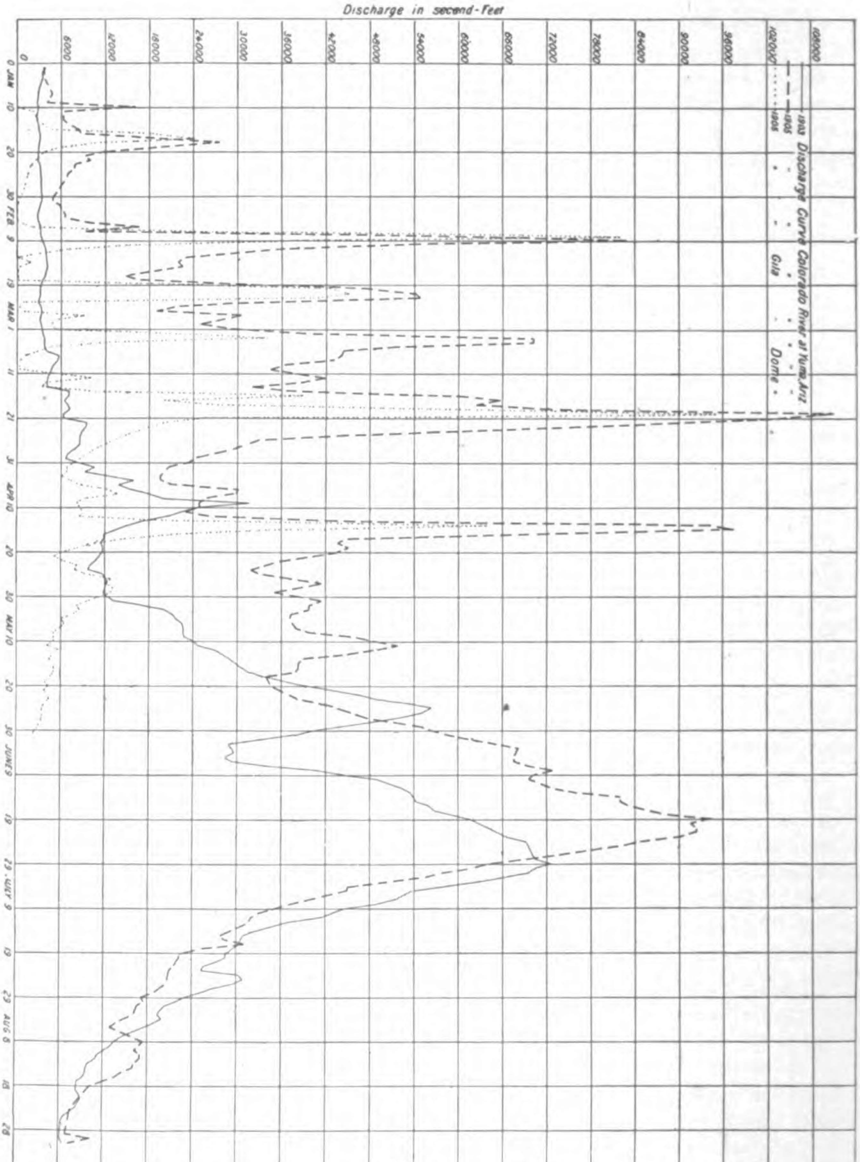


FIG. 8.—Diagram showing flood flow of Colorado and Gila rivers.

The flood of 1903 on the Colorado above Yuma is regarded as one of the largest recorded to that date. In the following table the monthly run-off, in acre-feet, during the floods of 1903 and 1905 are compared.

The following table gives a comparison of run-off in acre-feet of Colorado River at Yuma during the floods of 1903 and 1905:

Flow of Colorado River at Yuma, Ariz., in acre-feet, during floods of 1903 and 1905.

Month.	1903.	1905.	Month.	1903.	1905.
January	189,935	499,900	June	3,162,526	4,550,000
February	187,271	1,561,000	July	2,304,494	1,864,000
March	376,120	3,108,000	Total	9,147,086	16,426,900
April	852,456	2,251,000			
May	2,074,284	2,593,000			

The run-off for these seven months was 1.8 times greater in 1905 than in 1903.

The following table gives the greatest daily rate of flow at this station each year from 1894 to 1905:

Maximum daily rate of flow, in second-feet, of Colorado River at Yuma, Ariz., 1894–1905.[a]

Year.[b]	Date.	Discharge.	Year.	Date.	Discharge.
1894	June 15	34,700	1903	June 28	72,219
1895	May 23	35,550	1904	June 7	51,170
1896	June 9	38,100	1905	February 9	82,820
1897	do	55,300	1905	March 20	110,800
1898	June 27	33,100	1905	April 15	97,500
1899	June 29	52,700	1905	May 31	59,000
1900	June 10	54,400	1905	June 19	94,320
1901	July 1	63,450	1905	November 30	102,700
1902	May 26	59,200			

[a] This station is described in Water-Supply and Irrigation Paper No. 133, p. 25.
[b] Discharge prior to 1902 was obtained from the station rating curve of 1902.

The valley immediately above and below Yuma contains about 100,000 acres of irrigable land, and about 75,000 acres were covered by these floods. The damage done by the floods in the Yuma Valley proper—that portion on the east side of the river below Yuma—was estimated as follows:

Damage done in Yuma Valley by flood on Colorado River in 1905.

Crops	$50,000
Ditches, small levees land along the river, etc	10,000
Buildings	10,000
Canals	10,000
Total	80,000

The town of Yuma is well protected by levees, built by the Government after the great flood of the Gila in 1901.

FLOOD IN GILA BASIN, NOVEMBER, 1905.

There was a short but very large flood in the Gila from November 27 to December 2. The rate of flow and damage done far exceeded that during the spring floods.

PRECIPITATION.

The precipitation for the month of November in Arizona, as determined by the United States Weather Bureau at 56 stations, was nearly 4 inches above the average for November. There were three wet periods, one from the 4th to the 9th, a second from the 20th to the 23d, and the third from the 26th to the 28th. It was the rain of the third period that caused the flood. The daily precipitation from the 26th to the 28th and the total precipitation for the month are given in the following table for 26 places in the Gila and Little Colorado drainage basins:

Daily precipitation in Gila and Little Colorado River basins November 26–28, 1905, in inches.

Place.	November.			Sum.	Month of November.
	26.	27.	28.		
Jerome, Ariz	1.00	2.20	0.50	3.70	8.80
Prescott, Ariz	1.62	1.90	.61	4.13	8.68
Seligman, Ariz	.82	.61	....	1.43	4.83
Alma, N. Mex	....	1.10	....	1.10	5.70
Young, Ariz	2.10	1.16	....	3.26	8.36
Alpine, Ariz	.83	.26	....	1.09	6.30
Fort Apache, Ariz	1.45	.45	Tr.	1.90	4.64
Phoenix, Ariz	1.02	.49	....	1.51	3.61
Deming, N. Mex	.68	.01	....	.69	2.72
Fort Bayard, N. Mex	1.30	Tr.	....	1.30	3.66
San Carlos, Ariz	1.40	.20	....	1.60	4.04
Cambray, N. Mex	....	1.00	....	1.00	1.50
Dudleyville, Ariz	.80	.85	.62	2.27	5.65
Lordsburg, N. Mex	....	.61	....	.61	2.93
Mesa, Ariz	1.24	.14	....	1.38	3.55
Luna, N. Mex	1.05	.06	Tr.	1.11	6.01
Buckeye, Ariz	1.10	1.02	.02	2.14	5.01
Maricopa, Ariz	.89	.58	.18	1.65	3.47
Yuma, Ariz	1.14	....	....	1.14	2.44
Roosevelt, Ariz	Tr.	2.16	.46	2.62	5.21
Benson, Ariz	.32	....	....	.32	3.08
Duncan, Ariz	.85	.05	.05	.95	2.90
Holbrook, Ariz	1.01	.10	....	1.11	3.82
Kingman, Ariz	.48	.55	....	1.03	1.86
Flagstaff, Ariz	.98	1.74	.60	3.32	7.60
Tuba, Ariz	.12	.76	.06	.94	2.32

It can be seen from the above table that the precipitation at the headwaters of Gila, Salt, and Verde rivers was from 2 to 4 inches for the three days, November 26–28.

FLOW.

The following table gives the daily rate of flow of Colorado River at Yuma, Gila River at Dome and Cliff, the Salt at Roosevelt, and the Verde at McDowell during this flood:

Daily discharge, in second-feet, of Colorado, Gila, Salt, and Verde rivers during flood of November and December, 1905.

Date.	Colorado River at Yuma, Ariz.	Gila River at Dome, Ariz.[a]	Gila River at Cliff, N. Mex.	Salt River at Roosevelt, Ariz.	Verde River at McDowell, Colo.
November 26	6,580	180	419	2,150	1,610
November 27	6,650	480	13,640	97,710	61,460
November 28	24,500	780	9,835	45,250	13,120
November 29	62,500	95,000	6,700	14,050	5,520
November 30	102,700	36,900	4,515	9,480	4,240
December 1	77,360	30,700	3,190	8,700	3,280
December 2	37,160	24,400	2,387	4,700	2,400
December 3	40,200	18,200			
December 4	35,000	11,900			
December 5	28,650	5,700			
December 6	23,300	5,000			

[a] The stream was dry at this place from July 20 to September 13, and from October 19 to November 13, 1905.

NOTE.—Highest stage at Yuma, January-April, 1905, was 30.3 feet on March 20.

The greatest daily rate of flow of the Colorado at Yuma during this flood was 102,700 second-feet, only about 8,000 second-feet less than the daily rate on March 20, 1905.

The flow of the Gila at Dome reached a daily rate on November 26 of about 95,000 second-feet, the same as on March 20, 1905, and the same as the greatest daily rate during spring floods on this stream.

The flow of Salt River at Roosevelt reached a daily rate of 97,710 second-feet on the 27th, which is more than twice as great as the greatest rate of flow at this place during the spring floods of 1905. The water at this place rose to a stage of 35.8 feet—that is, 13 feet above that on April 13, 1905, when the rate of flow was the greatest during the spring floods. The mean daily stage on November 27 was 26.7 feet—that is, about 9 feet less than the maximum stage for that day. The maximum rate of flow on the morning of the 27th is estimated to have been 148,000 second-feet.

The greatest daily rate of flow of the Verde at McDowell was 61,460 second-feet on November 27, which is nearly twice as great as the greatest daily rate reached during the spring floods of 1905.

In places where the canyon was narrow the water rose to a height of 40 feet above low water. Verde and Tonto rivers reached a maximum stage earlier than Salt River, hence the Salt at Phoenix was not so high as in February, 1891, but indications seem to show that Salt River above the mouth of the Tonto was higher during this flood than at any time during its history.

DAMAGE.

The damage done by this flood on Salt River was very great. The bridges of the Gila Valley, Globe and Northern Railway and the Maricopa, Phoenix and Salt River Valley Railway across Gila River were swept away. The old Southern Pacific Railway bridge and the new Santa Fe Railway bridge across Salt River near Tempe and the approaches of the new Southern Pacific Railway bridge at Tempe were damaged. The Arizona dam and all other dams on Salt River were swept away. The water rose above the top of the head gates of the canal and greatly damaged the banks where the water passed back into

the river. The river rose 4 feet above the bridge at the gaging station at Roosevelt and swept it away. The flume and the cofferdam of the Roosevelt dam were swept completely away, and the Phoenix-Roosevelt road through the cañyon below the dam was badly damaged.

FLOOD ON LITTLE COLORADO RIVER IN NOVEMBER.

The excessive precipitation in the basin of the Little Colorado River November 26–28 (see p. 52) produced a sudden and large increase in the flow of this stream. The daily gage height and rate of flow at the gaging stations at Woodruff and Holbrook, Ariz., are given in the following table:

Flood flow of Little Colorado River at Woodruff and Holbrook, Ariz., November 26–30, 1905.

Date.	Woodruff, Ariz.		Holbrook, Ariz.	
	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
November 26	1.00	33	3.50	160
November 27	21.90	10,000	8.55	20,180
November 28	7.75	2,960	5.75	7,295
November 29	5.50	1,735	4.05	1,000
November 30	2.00	85	3.80	260

It is seen that the stage at Woodruff rose from 1 foot on the 26th to 21.9 feet on the 27th and the rate of flow from 33 second-feet to 10,000 second-feet.

At Holbrook the rate of flow increased from 160 second-feet to 20,180 second-feet in twenty-four hours.

FLOW OF COLORADO RIVER INTO SALTON SINK.

Salton Sink is a body of water in the southern part of California about 90 miles northwest of Yuma. It is noted for the fact that its surface is about 290 feet below sea level. Imperial Valley, in which it is located, has a length of about 90 miles and an area below sea level of about 1,000,000 acres. Much of the soil of this valley is very productive, and in order to irrigate it a channel was excavated from Colorado River to Alamo River, an old channel leading into the valley from a point just north of the California-Mexico boundary line, 10 miles below Yuma. This canal, which passes through material that is easily eroded, was left without head gates. It had a low grade and dredging was necessary to keep it open. In October, 1904, a cut-off channel 50 feet wide and 8 feet deep was excavated in Mexico from the river to the canal to procure a larger volume of water for irrigation. The floods from January to April, 1905, scoured the canal to some extent; the flood of May and June from the upper Colorado scoured it from a width of 100 feet to a width of 300 to 400 feet. As the latter flood subsided silt was deposited in the river channel below the canal headings and gradually closed the river channel.

The average fall of the Colorado from Yuma to the Gulf of California is about 1.25 feet per mile, and the average fall from the Colorado River to Salton Sink is about 3 feet per mile; and as the canal passes through material that is easily eroded, cutting of bed and banks took place rapidly. On June 30, 1905, 22 per cent of the river flow was passing into the canal. On July 8, 67 per cent passed into the canal, and October 25 the whole flow passed into the canal. In November an effort was made to turn the river away from the canal by constructing a diversion dam of brush, piles, and gravel, but the sudden large November flood (p. 53) swept away the dam and greatly widened and deepened the cut-off canal. An attempt was also made to divert the flow of the Alamo canal back into the gulf by a short channel to Padrone River, which flows into Volcano Lake. A dam was built across New River at the lower end of this lake to force the lake to discharge

to the southeast, into the gulf, instead of through New River into Salton Sink. Padrone River, however, cut a new channel across the country to New River, and thus the water passed into the sink instead of into the gulf. Near the close of 1905 the water in the sink was described as 45 miles long, from 10 to 18 miles wide, and 23.5 feet in greatest depth. It is reported that the water in the sink rose at the rate of one-half to three-fourths of an inch a day and during the larger floods at the rate of 2 inches a day.

The works of the New Liverpool Salt Company, located on the shores of the sink, have been drowned out. At the close of 1905 the water was up to the roofs of the buildings. The Southern Pacific Railway has 60 miles of main line and 40 miles of branch lines in this valley below sea level. Up to February, 1906, 40 miles of new track had been laid by this company 50 feet above the old location. It is said that $25,000 were spent on the construction of the diversion dam at the entrance to the canal that was swept away by the November flood.

The most serious danger to this valley is that before the river is controlled the canal may be cut so deep that water can not be taken from it to the irrigable land by gravity.

UNUSUAL RATES OF RUN-OFF IN 1905.

The following unusual rates of run-off occurred in the United States in 1905:

Extraordinary rates of run-off in 1905.

Stream and place.	Drainage area.	Date.	Maximum rate.
	Sq. miles.		*Sec.-feet.*
Mill Brook near Edmeston, N. Y.	9.4	September 3-4	241
Mad Brook near Sherburne, N. Y.	5.0	September 3-4	262
Starch Factory Creek near Utica, N. Y.	3.4	September 3	209
Do	3.4	June 21	190
Six-Mile Creek near Ithaca, N. Y.	46.0	June 21	195

FLOOD DISCHARGE AND FREQUENCY IN THE UNITED STATES.

INTRODUCTION.

Water-Supply Paper No. 147, "Destructive floods in the United States in 1904," pages 184–189, gives the greatest rate of flow of the largest recorded flood on many streams in this country. The following pages contain data on the daily rate of flow and frequency of all the larger floods on some streams. These streams are selected in preference to others on account of the long record of flood observation on them. The periods over which the flood records extend vary from eleven to more than one hundred years. The source of information is given in each compilation; when no statement to the contrary is made, the data were obtained by engineers and hydrographers of the United States Geological Survey.

A brief description of each drainage basin is given, especially of the part above the gaging station where the data were obtained, with a statement of the features that influence flood flow. Brief notes calling attention to the more important facts shown by the data are also presented.

At flood flow a stream usually carries much drift, overflows its banks, and changes height rapidly, so that it is very difficult to measure accurately its discharge at maximum stage. Some of the data here given are computed from careful measurements made during or shortly after the flood and some are computed from a single station rating curve, assuming the channel conditions to have been fairly constant during the period considered.

Primarily the flood flow of a stream depends on—

(1) The extent, duration, and intensity of precipitation, especially the intensity in the case of small drainage basins.

(2) The direction of motion of the storm causing the flood. If the storm moves in the direction of the flow of the stream the flow will be greater than if it moves in the opposite direction or across it.

(3) The amount of snow on the ground and the temperature during the storm. The large floods on northern streams are due almost entirely to the rapid melting of snow. When the ground is frozen the measured run-off is occasionally more than three times the precipitation during the month.

(4) The storage, both natural and artificial, in the drainage basin. In some basins ground storage may take up 9 inches of precipitation. Storage extends the flood period and reduces the maximum rate of flow.

(5) The size of the drainage basin. Most great rainstorms cover comparatively small areas, so that a big storm is likely to cover a larger part of a small drainage basin than of a large one. The maximum rate of discharge per square mile will therefore increase as the size of the drainage basin decreases.

(6) The physiography of the drainage basin. The maximum rate of flow from a comparatively long and narrow basin with tributaries entering a considerable distance apart will be less than from a basin of nearly circular shape of the same size but with tributaries entering the main stream in close proximity. Steep, impervious, deforested slopes of basin and steep slope of stream bed cause rapid run-off. Narrow, deep, crooked channels of small slope cause sluggish flow, great variations in stage, and frequent overflow.

Among the more or less artificial conditions that increase the flow may be mentioned—(1) controlled storage; (2) deforestation and cultivation; (3) reduction in width of channel by placing the abutments of bridges in the stream; (4) the use of piers that prevent scour of bed, collect drift, and hold back a part of the flow for a time, causing greatly increased flood wave; (5) the formation of ice gorges and the failure of dams and reservoir walls.

KENNEBEC RIVER.

Kennebec River is the outlet of Moosehead Lake, in northwestern Maine. The basin has a length of 150 miles, a width of 50 to 80 miles, and an area of 6,330 square miles. Its upper part is mountainous and thickly forested; its lower part is hilly or gently rolling, with grass-covered slopes. In this basin are 360 square miles of lake storage, controlled mainly by dams at the outlet of each lake. This stored water is used principally for log driving. From Moosehead Lake to Augusta, the head of navigation, a distance of 112 miles, the stream has an average fall of 9.1 feet per mile.

The following table gives the daily rate of flow of this stream at the Hollingsworth & Whitney Company's dam at Waterville, Me., during the greatest annual floods, from 1893 to 1904.

Flood flow of Kennebec River at Waterville, Me., from 1893 to 1904.

[Drainage area above this gaging station, 4,380 square miles.]

Year.	Date.	Discharge.[a]	Year.	Date.	Discharge.[a]
		Sec.-feet.			*Sec.-feet.*
1893	May 18	83,500	1898	April 15	50,390
1894	April 23	35,280	1899	April 27	45,800
1895	April 15	86,200	1900	April 21	62,290
1896	March 1	6,260	1901	April 9	76,600
1896	March 2	111,200	1902	March 4	54,340
1896	March 3	52,690	1903	March 20	35,700
1896	March 4	24,810	1904	May 12	37,840
1897	April 8	66,900			

[a] Data furnished by Hollingsworth & Whitney Company.

The largest flood in these fifteen years at Waterville occurred on March 2, 1896, when the rate of flow for the day was 111,200 second-feet, or 25.2 second-feet per square mile. The rise was exceedingly rapid, the discharge increasing from about 6,000 to 111,000 second-feet in twenty-four hours.

The greatest flood in the upper part of this basin occurred on December 15, 1901. At 8 a. m. only a few second-feet of water were flowing over the dam at Madison, Me., where the drainage area is 2,850 square miles. At midnight the depth of water on the crest of this dam was 14.5 feet and the rate of flow was 105,000 second-feet. At 9 a. m. the next day the water surface had fallen 5.5 feet.

The large floods in this basin all occur in the spring or winter and are due to rain and the rapid melting of the winter accumulations of snow. The summer floods are small compared with the spring floods.

ANDROSCOGGIN RIVER.

The Androscoggin is the outlet of the Umbagog-Rangeley lakes in western Maine. The basin has a length of about 110 miles, a greatest breadth of 70 miles, and an area of 3,700 square miles. The upper part of the basin is mountainous, broken, and thickly forested; the lower part is hilly, with grass-covered or cultivated slopes. There are 148 lakes in the basin, having a water-surface area of 312 square miles—that is, about one-twelfth of the basin is water surface. From the foot of Umbagog Lake to the foot of Rumford Falls, a distance of 81 miles, the stream falls 836 feet. The lakes are largely controlled by dams and the storage is used mainly for log driving. The range of stage at Lewiston near the mouth is 8 feet; at Bethel, 28 feet.

The following table gives the daily rate of flow of this stream at Rumford Falls, Me., during the greatest annual floods, from 1893 to 1903:

Flood flow of Androscoggin River at Rumford Falls, Me., from 1893 to 1903.

[Drainage area above gaging station, 2,320 square miles.]

Year.	Date.	Discharge.[a]	Year.	Date.	Discharge.[a]
		Sec.-feet.			*Sec.-feet.*
1893	May 18	38,060	1899	May 2	24,080
1894	April 21	22,230	1900	May 20	24,530
1895	April 22	55,230	1901	April 22	32,650
1896	April 17	27,390	1902	March 30	18,490
1897	July 15	22,900	1903	June 13	26,790
1898	April 25	16,750			

[a] Data furnished by C. A. Mixer, C. E., resident engineer of the Rumford Falls Power Company.

The greatest flood on this stream at this place in these twelve years occurred April 22, 1895. The greatest daily rate of flow was 55,230 second-feet, or 23.8 second-feet per square mile.

The larger floods in this basin occur in the spring and are due to rain and the rapid melting of snow. As a rule, the floods on this river are somewhat less in magnitude than those on the Kennebec.

MERRIMAC RIVER.

The Merrimac is formed by the union of the Pemigewasset and the Winnepesaukee rivers at Franklin, N. H. The basin is comparatively long and narrow and has an area of 4,916 square miles. The upper part is mountainous, broken, and forested; the central part is hilly or gently rolling, cultivated and pasture lands; the lower part is flat, with some

swamps. There are in this basin more than 100 square miles of controlled storage. From its head at Franklin Junction to its mouth, a distance of 110 miles, the river falls 269 feet.

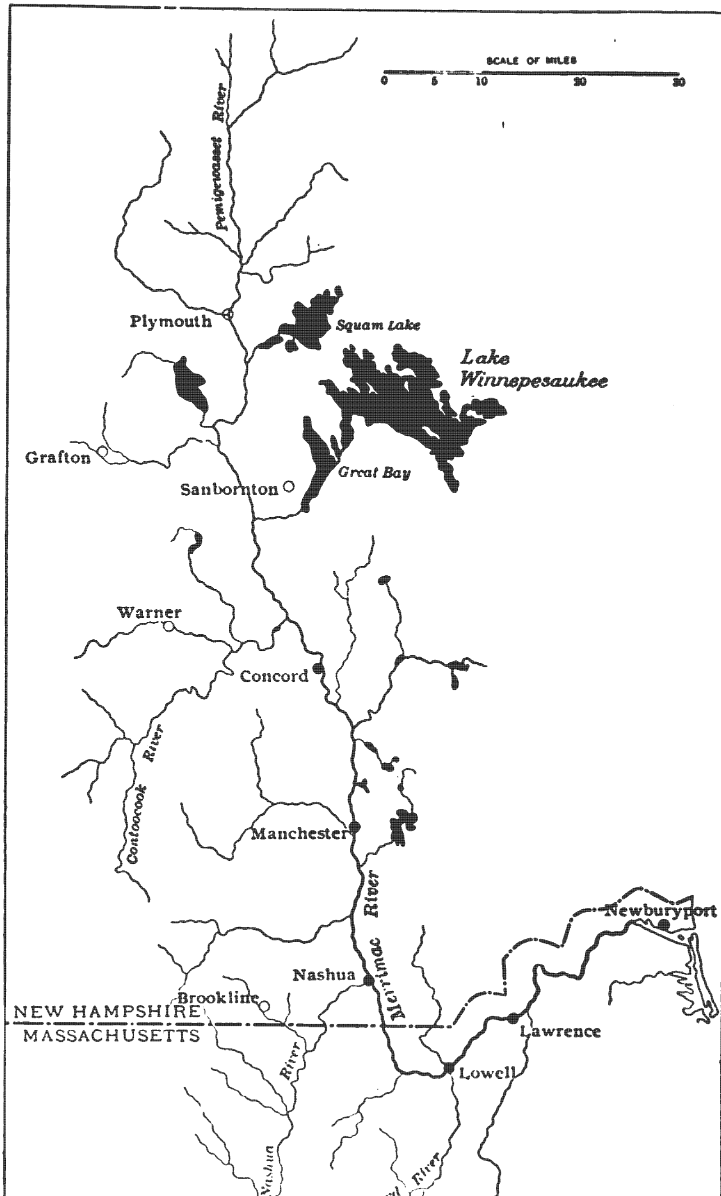


FIG. 9.—Map of drainage basin of Merrimac River.

A large part of this total fall is concentrated at six places. Along the stream are extensive tracts of bottom land, which are subject to overflow during floods.

The following table gives the daily rate of flow and dates of occurrence of the larger floods since 1846 at Lawrence, Mass.:

Flood flow of Merrimac River at Lawrence, Mass., 1846 to 1904. [a]

[Drainage area, 4,553 square miles.]

Year.	Date.	Discharge.[a]	Year.	Date.	Discharge.[a]
		Sec.-feet.			*Sec.-feet.*
1846	Spring [b]		1900	February 15	52,990
1852	Spring [c]		1901	April 7	33,950
1890	October	31,450	1901	April 8	61,200
1892	May	32,800	1901	April 9	62,510
1893	May	44,800	1901	April 10	48,760
1894	March	27,900	1901	April 11	38,020
1895	April	65,300	1901	April 12	31,460
1896	March	82,150	1902	March 4	61,190
1897	July	41,500	1903	March 13	45,470
1898	March 15	36,000	1904	May 1	46,340
1899	April 17	38,200			

[a] Data furnished by R. A. Hale, engineer, Essex Water Power Company.
[b] Largest flood in recollection of inhabitants.
[c] Stage was 0.8 foot lower than in 1896.

The greatest flood since 1846 occurred March, 1896. On March 3 the stage at Lawrence was 25 feet above low water, and the maximum rate was 82,150 second-feet, or 18 second-feet per square mile. This was the spring flood and was largely due to rapid melting of snow. The floods due to rain alone are scarcely half the magnitude of the spring floods. The spring floods generally last from one to two weeks.

CONNECTICUT RIVER.

Connecticut River has its source in Connecticut Lake in northern New Hampshire. It falls from an elevation of 1,618 feet to nearly sea level at Hartford in a distance of about 312 miles. The basin, shown in fig. 10, is long and narrow and has an area of 10,924 square miles. The upper part is mountainous, with some forest area; the middle and lower

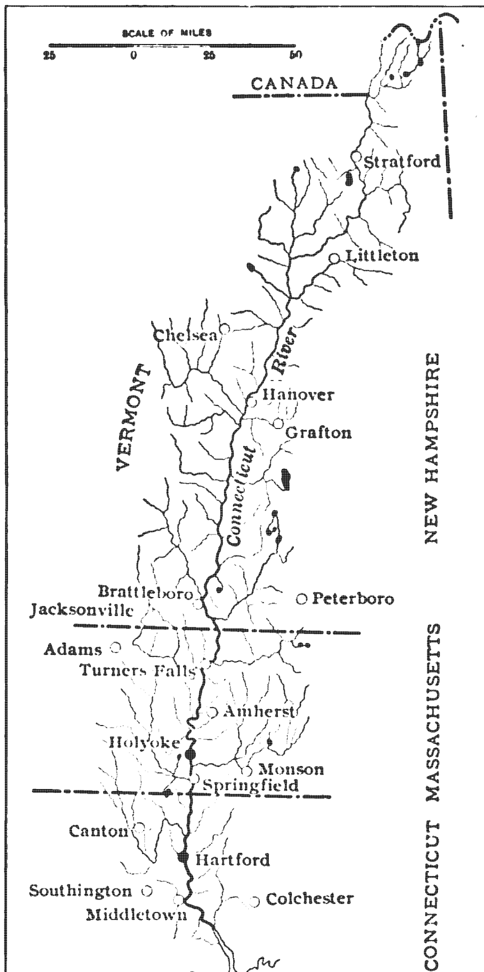


FIG. 10.—Map of drainage basin of Connecticut River.

parts are hilly or rolling—grass covered or cultivated. The river receives the water of many small tributaries and a small amount from lake storage. Above Bellows Falls the stream has numerous shoals and rapids; below this place its descent is much slower and is broken by rapids at only three places.

The following table gives the daily rate of flow and date of occurrence of the large floods on this stream at Hartford, Conn., since 1801:

Flood flow of Connecticut River at Hartford, Conn., 1801-1904.

[Drainage area, 10,234 square miles. Danger line, 13 feet gage height.]

Year.	Month.	Gage height.[a]	Discharge.[b]	Year.	Month.	Gage height.[a]	Discharge.[b]
		Feet.	Sec.-feet.			Feet.	Sec.-feet.
1801..		27.5	178,400	1878.	December	23.9	138,200
1841..		26.3	164,700	1879.	May	21.4	113,500
1843..		27.2	175,000	1884.	April	21.5	114,400
1847..	April	21.0	109,800	1886.	May	21.8	117,200
1850..	May	20.8	108,100	1887.	April	22.5	124,000
1852..	April	23.1	129,800	1888.	April	19.4	96,060
1853..	November	20.5	105,400	1889.	November 30	15.6	68,140
1854..	May	29.8	205,200	1890.	October 26	16.0	70,700
1856..	August	23.3	131,900	1891.	April 17	19.8	99,420
1859..	March	26.4	165,900	1892.	June 16	18.3	87,100
1861..	April	21.5	114,400	1893.	May 6	24.0	139,200
1862..	April	28.7	192,300	1894.	April 25	13.8	
1865..	March	24.8	147,800	1895.	April 16	25.7	157,900
1866..	February	20.5	105,400	1896.	March 3	26.5	167,000
1867..	April	20.0	101,100	1897.	July 16	20.8	108,100
1868..	March	21.5	114,400	1898.	March 22	21.2	110,700
1869..	April	26.7	169,300	1899.	April 27	[c] 22.0	119,100
1869..	October	26.3	164,700	1900.	February 15	23.4	133,000
1870..	February	21.3	112,600	1900.	April 22	22.8	126,900
1870..	April	25.3	153,400	1901.	April 25	22.7	125,900
1873..	April	21.0	109,800	1902.	March 4	25.5	155,600
1874..	January	23.9	138,200	1903.	March 25	23.4	133,000
1876..	April	21.9	118,200	1904.	April 30	21.4	113,500
1877..	March	22.9	127,800	1905.	March 31	22.8	126,900

[a] Furnished by Edwin Dwight Gravus, chief engineer Connecticut River bridge and highway district.
[b] Computed from rating table prepared by T. G. Ellis, C. E., Report Chief of Engineers U. S. Army, 1875, pt. 2, p. 364.
[c] From April 16 to April 31 the stage did not fall below 20 feet.

The flood of May, 1854, was the largest in more than a century, and reached a stage of 29.8 feet above low water at Hartford, Conn. The daily rate was 205,460 second-feet, or 20 second-feet per square mile.

The flood of April, 1862, was the largest at Holyoke, Mass., and gave a discharge of 162,000 second-feet, or 18.7 second-feet per square mile.

The largest flood that was due entirely to rain occurred in October, 1869. The maximum daily rate of flow was 16.5 second-feet per square mile. High stages in the spring sometimes last for two or more weeks.

HUDSON RIVER.

The drainage basin of Hudson River above the gaging station at Mechanicsville, N. Y., comprises 4,500 square miles. It is mountainous, with considerable lake storage and forest area.

Serious flood conditions exist in a stretch of the river extending for 30 miles below Albany. Here the channel is shallow, narrow, and crooked, and there is a tidal action and a large inflow from the Mohawk. The tidal action prevents the rapid passing out of ice, and aids in the formation of ice dams. Floods due to ice come with but little warning at any time from December to April.

The following table gives the rate of flow and date of occurrence of each of the large floods at Mechanicsville, N. Y., since 1869:

Flood flow of Hudson River at Mechanicsville, N. Y., 1869-1904.[a]

[Drainage area, 4,500 square miles. Danger line, 9.0 feet gage height.]

Year.	Date.	Discharge	Year.	Date.	Discharge.
		Sec.-feet.[b]			*Sec.-feet.*
1869....	Spring........................	70,000	1902...	March 3........................	41,360
1896....	April 18........................	42,620	1903...	March 23........................	42,910
1896....	November 7........................	24,550	1903...	March 24........................	54,490
1898....	March 14........................	39,230	1903...	March 25........................	56,280
1899....	April 26........................	41,480	1903...	March 26........................	50,640
1900....	April 23........................	43,550	1903...	March 27........................	41,580
1901....	April 23........................	54,860	1903...	March 28........................	32,930

[a] Data furnished by the Duncan Company, R. P. Bloss, engineer.
[b] Hydrology of the State of New York, 1905, p. 467.

The largest flood in these thirty-five years was in the spring of 1869, when the discharge was 70,000 second-feet, or 15.6 second-feet per square mile. The large floods all occur in the spring, and are due to rapid melting of the winter accumulation of snow with rain.

GENESEE RIVER.

Genesee River rises in northern Pennsylvania, flows northward across New York State, and empties into Lake Ontario. Its basin is 108 miles long, 22 miles wide, and comprises 2,400 square miles. The catchment area above Mount Morris has steep slopes with heavy and impervious soil and little wooded area. In the catchment area below Mount Morris there are from 60 to 80 square miles of flats subject to overflow. These flats act as a reservoir, decreasing to a marked degree the maximum rate of flow at Rochester. Near Portage the river passes through a narrow canyon and has a fall of 330 feet, nearly all of which is at Portage Falls.

The following table gives the daily rate of flow of this stream at Rochester, N. Y., of the large floods from 1785 to 1904, and the date of occurrence of each:

Flood flow of Genesee River at Rochester, N. Y., 1785-1904.[a]

[Drainage area, 2,428 square miles.]

Year.	Date.	Place.	Discharge.	Year.	Date.	Place.	Discharge.
			Second-feet.				*Second-feet.*
1785..	....	Rochester.....	40,000	1894.	May 18....	Mount Morris..	600
1835..	October...	Rochester.....	36,000	1894.	May 19....	Mount Morris..	5,530
1857..	February.	Rochester.....	30,000-35,000	1894.	May 20....	Mount Morris..	16,580
1865..	March....	Rochester.....	45,000-54,000	1894.	May 21....	Mount Morris..	42,000
1867..	February.	Rochester.....	20,000-25,000	1894.	May 22....	Mount Morris..	33,000
1873..	March....	Rochester.....	30,000-35,000	1894.	May 23....	Mount Morris..	15,650
1875..	March....	Rochester.....	30,000-35,000	1894.	May 24....	Mount Morris..	7,300
1879..	March....	Rochester.....	20,000	1896.	April.....	Rochester.....	33,000-36,000
1889..	June.....	Rochester.....	20,000	1902.	March....	Rochester.....	35,000-38,000
1890..	September	Mount Morris.	20,000	1902.	July......	Portage.......	40,000-50,000
1893..	March....	Mount Morris.	30,000	1903.	April 5....	Rochester.....	18,380

[a] Report of special committee on flood conditions in the Genesee River affecting the city of Rochester, N. Y., 1904.

The greatest rate of flow during this period at Rochester was during the flood of March, 1865, when the rate per square mile of drainage was 19 to 22 second-feet. This was a spring flood and was due largely to the rapid melting of snow.

The flood of May, 1894, which gave a maximum rate at Mount Morris of 42,000 second-feet, gave a maximum rate of only 20,000 to 21,000 second-feet at Rochester.

The flood of July 5–9, 1902, was without precedent in the high stage of water for the time of year and the damage done. The ground was saturated at the time. The precipitation for June and July was more than 12 inches over half of New York State and 18 inches at some stations in this basin.

PASSAIC RIVER.

The topography of this watershed has a marked effect on the flood flow of the stream and on the damage resulting from overflows. The watershed is fan shaped, consisting of a large central basin with a narrow outlet. The length of the stream from source to mouth is only 27 miles, but the length by river is 83. The total drainage area is 949 square miles, the area above Little Falls, the outlet of the central basin, is 772.9 square miles. All the important tributaries except one drain highland areas having steep, nearly impervious slopes and empty into the central basin. This basin is 8 to 12 miles wide, 32 miles long, and contains 29,300 acres. Much of it is marshy or wet land, flooded during ordinary freshets. As the outlet of this basin is too small to allow free flow from it, the water is held back for a time and the duration of each flood is increased.

The fall from this outlet to the ocean is mainly concentrated at three places, leaving little fall between. The channel cross section in part of the lower reach is also small.

The following table gives the daily rate of the flow of this stream at Dundee dam during the large floods from 1877 to 1903 and the date of occurrence of each:

Flood flow of Passaic River at Dundee dam, New Jersey, 1877–1903.

[Drainage area, 822.7 square miles.]

Year.	Date.	Maximum discharge.	Duration in hours.	Year.	Date.	Maximum discharge.	Duration in hours.
		Sec.-feet.				*Sec.-feet.*	
1877	March 29	10,780	60	1889	April 29	10,970	66
1878	September 12	16,590	60	1891	January 24	11,700	60
1882	September 25	18,260	60	1893	March 14	11,220	69
1886	February 14	12,450	60	1893	March 6	11,160	72
1886	April 8	10,420	55	1902	March 2	24,800	270
1888	February 3	11,880	68	1903	October 10	35,000	225
1888	September 21	11,130	72				

NOTE.—Records for years preceding 1902 are from Report Geol. Survey, New Jersey, 1894, vol. 3, p. 53; records for 1902 and 1903 are from Water-Supply and Irrigation Paper U. S. Geological Survey No. 92, p. 19.

The largest spring flood during this period occurred from February 27 to March 6, 1902.[a] The maximum rate of flow was 30.2 second-feet per square mile. This flood was due to melting snow, accompanied by rain on frozen ground.

The largest flood due to rain alone occurred October 7–10, 1903,[b] when the maximum rate of flow was 43.4 second-feet per square mile—that is, 44 per cent greater than that of March 2, 1902. The precipitation for the three days October 8–11 over this watershed was 11.74 inches. The precipitation during the preceding months was above the normal, so that the ground and surface reservoirs could absorb only a small part of the water that fell during the storm.

[a] This flood and the damage wrought by it is treated in Water-Supply and Irrigation Paper No. 88.
[b] This flood and the damage wrought by it is treated in Water-Supply and Irrigation Paper No. 92.

RARITAN RIVER.

The Raritan is the largest river of New Jersey. Its basin is long and narrow and comprises an area of 1,105 square miles. The upper part is mountainous and has a rapid run-off. The lower part is hilly or rolling with grass-covered or cultivated slopes. Less than 13 per cent of the whole area is forested. The topography of this basin is very different from that of the Passaic, which lies just north of it. The rain falling on all parts of the basin runs off quickly, so that the floods are shorter than in the Passaic and inflict less damage.

The following table gives the daily rate of flow of this stream during the large floods from 1810 to 1905, and the date of occurrence of each:

Flood flow of Raritan River at New Brunswick and Boundbrook, N. J.[a]

[Drainage area above Boundbrook, 806 square miles.]

Year.	Date.	Gage height.	Discharge.	Year.	Date.	Gage height.	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1810	November 24	([b])			October 10	[e] 12.0	28,500
1865	July 17	([b])			October 11	[e] 6.5	10,840
1874	September 18	9.0			October 12	[e] 5.2	7,500
1882	September 22		[d] 7,000		October 13	[e] 3.5	3,800
	September 23	[c] 11.5	[d] 35,500	1904	February 22	9.5	19,950
	September 24	[c] 14.2	[d] 52,000		September 15	10.1	21,940
	September 25		[d] 7,000		September 16	5.5	8,230
1886	February 12	[c] 9.0		1905	January 7	10.4	22,960
1887	February 23	[c] 8.0			January 8	5.7	8,730
1889	November 28	[c] 8.0			March 9	6.0	9,500
1903	October 8	[e] 1.6	820		March 10	7.4	13,410
	October 9	[e] 7.9	14,900		March 11	5.7	8,730

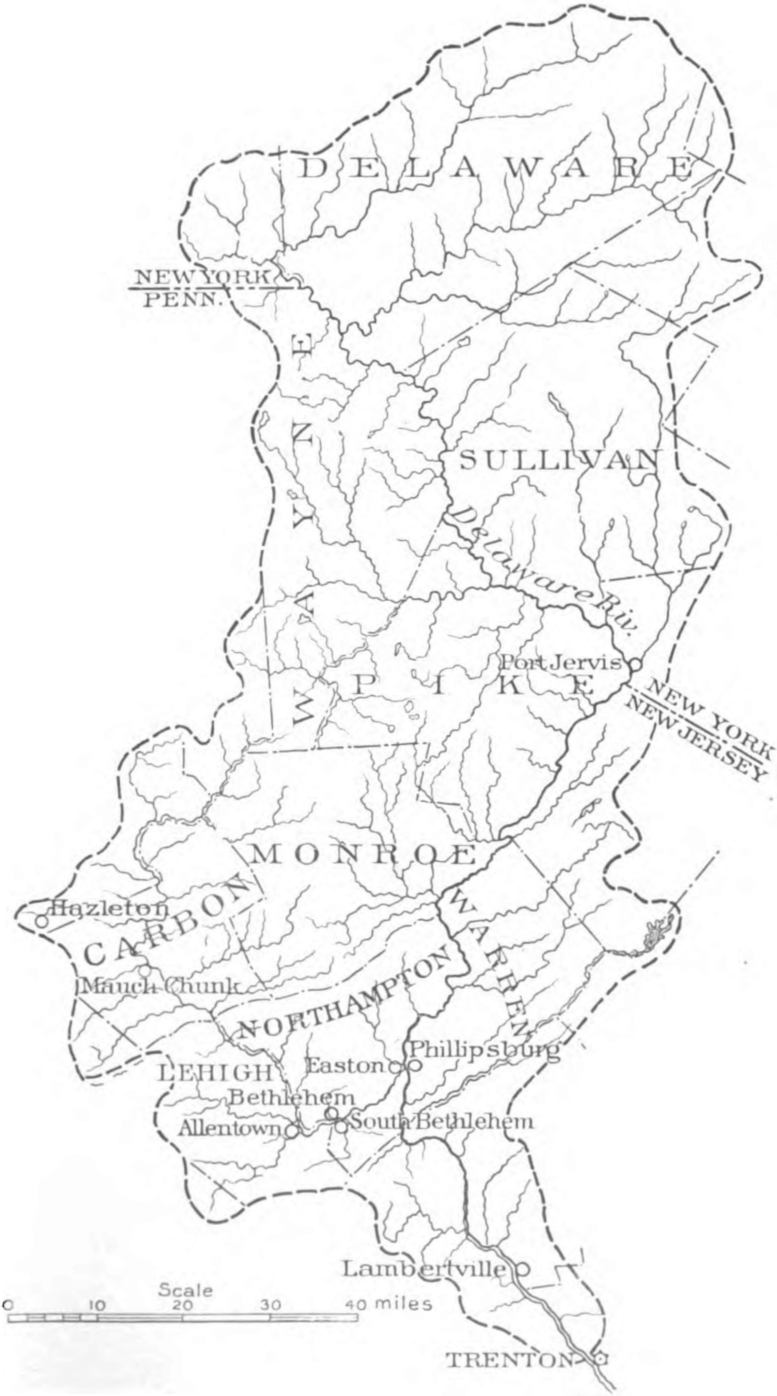
[a] A description of this station is given in Water-Supply and Irrigation Paper No. 97, p. 238.
[b] Not as great as in September, 1882.
[c] At Boundbrook dam.
[d] Geological Survey, New Jersey, 1894, vol. 3, p. 213.
[e] U. S. Geological Survey gaging station, Boundbrook, N. J.

There were four great floods in these ninety-five years. That of September 24, 1882, which had a maximum discharge at Boundbrook of 52,000 second-feet, or 64.5 second-feet per square mile, was probably the largest during this period. It was due to a long, heavy rain. During four days 12 inches of rain fell over this basin.

During the great flood in the Passaic River basin in October, 1903, the maximum rate of flow of the Raritan at Boundbrook was only 28,500 second-feet, or 35.3 second-feet per square mile.

DELAWARE RIVER.

The Delaware rises in the southeastern part of New York State, on a plateau that stands 1,800 to 1,900 feet above sea level, flows in a general southerly direction a distance of 410 miles, and empties into Delaware Bay (see Pl. III). From its source to Trenton, N. J., a distance of 280 miles, its average fall is 6.7 feet per mile. The basin is long and narrow, with steep slopes and little surface storage above Lambertville, N. J. The topographic features all favor a rapid run-off, hence the stream is subject to great and sudden fluctuations of flow.



DRAINAGE BASIN OF DELAWARE RIVER.

The following table gives the daily rate of flow of this stream at or near Lambertville, N. J., of the large floods from 1786 to 1905.

Flood flow of Delaware River at Lambertville, N. J.[a]

[Drainage area, 6,855 square miles.]

Year.	Date.	Gage height.[b]	Discharge.	Year.	Date.	Gage height.[b]	Discharge.
		Feet.	*Second-feet.*			*Feet.*	*Second-feet.*
1786	October 6......	16.0	175,000	1902	March 3........	16.4	132,600
1801	....	14.0	140,000-160,000		March 4........	12.5	92,450
1814	....	14.0	115,000		March 5........	9.4	60,470
1832	March.........	12.0	115,000		March 14.......	11.1	77,980
1836	April..........	14.5	140,000-150,000		March 15.......	10.2	68,710
1839	April..........	14.6	140,000-150,000		March 18.......	11.8	85,190
1841	January 8.....	20.0	254,600	1903	March 1........	13.6	103,700
1843	October 13.....	14.0	140,000-150,000		March 2........	12.9	96,520
1846	March 15.......	17.6	207,000		March 24.......	12.7	94,460
1862	June 8.........	....	223,600		March 25......	12.4	91,370
1890	November 5...	....	50,200		October 9.....	9.4	60,470
1891	January.......	....	109,100		October 10....	20.2	171,700
1899	March 7........	9.7	63,560		October 11....	20.7	176,900
1900	February 14...	11.4	81,070		October 12.....	12.7	94,460
	March 2........	12.0	87,250		October 13.....	9.9	65,620
1901	March 22.......	10.5	71,800	1904	February 21...	[c] 10.0	....
	December 16...	18.9	158,300		February 22...	[c] 15.1	....
1902	March 1........	18.2	151,100		February 23...	[c] 13.5	....
	March 2........	20.2	171,700	1905	March 28.......	11.9	86,220

[a]This station is described in Water-Supply and Irrigation Paper U. S. Geological Survey, No. 97 p. 249.
[b] Heights given for 1786 to 1846 are heights above low water. See Rept. New Jersey Geol. Survey for 1894, vol. 3, p. 235; and Rept. of Chief Engineer U. S. Army for 1873, App. U, p. 19. Discharges have been computed from the gage heights given.
[c] Due to ice gorge.

According to these records the largest flood on this stream since 1786 occurred January 8, 1841, during which the rate of flow was 254,600 second-feet, or 37.1 second-feet per square mile. The largest in recent years was the great flood of October, 1903, the rate on the 11th being 176,900 second-feet, or 25.8 second-feet per square mile. The storm that produced the flood on this stream caused an unprecedented flood on the Passaic River.[a]

[a] Water-Sup. and Irr. Paper No. 92, U. S. Geological Survey, 1904.

SUSQUEHANNA RIVER.

The Susquehanna, the largest river on the Atlantic slope, rises in Otsego Lake, New York, at an elevation of about 1,193 feet above sea level. It falls this height in 422 miles, but its fall per mile, unlike that of most streams, is greater in the 43 miles just above its mouth than in any other part of its course. In these 43 miles it falls 231 feet.

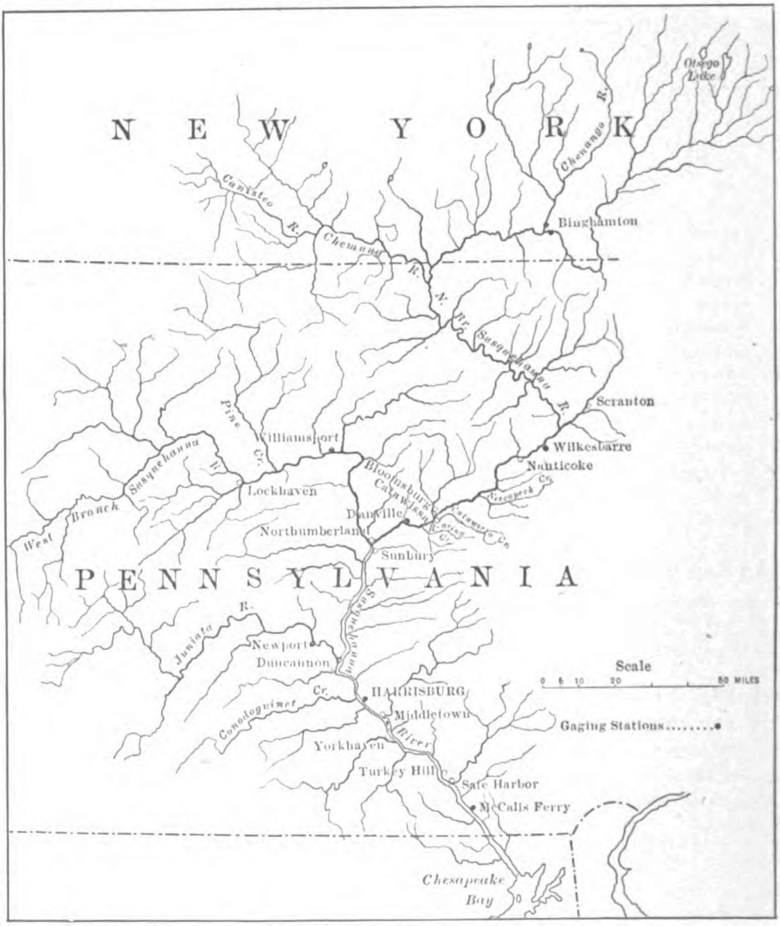


FIG. 11.—Map of drainage basin of Susquehanna River.

The basin is fan shaped, being nearly as broad as it is long, and has an area of 27,400 square miles. Its topography is extremely varied in character. The upper part is a plateau—a rolling country with moderately rapid run-off. Nearly all the remainder is mountainous, with steep slopes, little forest area, little surface storage, and comparatively little ground storage. Spring freshets, due to the rapid melting of the winter's snow and to ice gorges in the streams, are of frequent occurrence.

The following table gives the daily rate of flow at Harrisburg during the large floods that have occurred from 1865 to 1905, and the date of each:

Flood flow of Susquehanna River at Harrisburg, Pa., 1865–1905.[a]

[Drainage area, 24,030 square miles. Danger line, 17 feet gage height.]

Year.	Date.	Gage height.	Discharge.	Year.	Date.	Gage height.	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1865	March		([b])	1901	December 17	18.6	323,380
			670,000		December 18	14.2	215,720
1889	June		to		December 19	9.8	134,900
			735,000	1902	February 28	9.7	133,150
1891	February 18	14.3	217,580		March 1	20.3	371,950
	February 19	19.0	234,500		March 2	23.9	483,760
	February 20	17.8	301,460		March 3	23.3	464,320
	February 21	13.3	198,700		March 4	21.4	404,800
1893	May 4	6.8	82,900		March 5	16.3	262,240
	May 5	16.2	259,660		March 6	12.3	179,960
	May 6	16.5	267,400	1903	March 1	13.4	200,600
	May 7	14.6	223,240		March 2	16.8	275,200
1894	May 21	16.3	262,240		March 3	14.5	221,300
	May 22	25.6	540,720	1904	March 5	[c]128.0	141,100
	May 23	21.4	404,800		March 6	[c]128.0	141,100
	May 24	15.3	237,780		March 7	[c]126.4	118,500
1898	March 23	10.9	154,480		March 8	[c]146.6	[d]300,000
	March 24	15.6	244,740		March 9	[c]130.2	176,500
	March 25	15.3	237,780		March 10	[c]130.4	180,700
	March 26	11.7	168,980		March 11	[c]130.9	192,000
1901	December 15	9.3	126,050	1905	March 21	15.7	283,700
	December 16	21.4	404,800				

[a] For description of gaging station and station rating table see Water-Sup. and Irr. Paper No 109, pp. 104 and 115.
[b] Approximately the same as during flood of June, 1889.
[c] At McCall Ferry. Above sea level.
[d] Approximate maximum discharge, 631,000 second-feet.

Four very large floods have occurred during this period. Two of these occurred in March and were due to rapid melting of snow and to ice gorges, and two occurred later in the year and were due to rainfall alone. The flood of June, 1889, was the largest and had a maximum rate of from 28 to 30.6 second-feet per square mile at Harrisburg. The storm causing this flood lasted about thirty-four hours. During this time from 4 inches to 9 inches of rain fell.[a]

This flood reached a stage of 33.5 feet above low water at Williamsport, on the West Branch. The highest stage at this place during the flood of 1865 was 27 feet.

This flood was very large on Chemung River, a northern tributary of the Susquehanna. The maximum rate of flow at Elmira on June 1 from 2,055 square miles was 67 second-feet per square mile.[b]

The flood of March, 1904, is described in Water-Supply Paper No. 147, pages 22 to 32.

POTOMAC RIVER.

The Potomac is formed by the union of its north and south branches 15 miles below Cumberland, Md. From Cumberland to Georgetown the river falls 610 feet in 185 miles. The basin is long and comparatively narrow and has an area of 14,500 square miles. The basins of both branches of the Shenandoah, its principal tributary, are also long and narrow. The greater part of the Potomac basin is mountainous, with steep, nearly impervious slopes, little forest area, and no surface storage. All the topographic features favor rapid run-off; hence floods are frequent, sudden, and large. The valley of the Shenandoah is somewhat broader than that of the Potomac, and the range of surface fluctuation of the stream is not so great.

[a] Rept. Chief Engr. U. S. Army, 1891, p. 1105. Also Eng. News, vol. 21, p. 528.
[b] Report of Francis Collingwood on "Protection of Elmira, N. Y. against floods."

The following table gives the daily rate of flow of this stream during the large floods from 1889 to 1905 and the date of occurrence of each:

Flood flow of Potomac River at Point of Rocks, Md., 1889–1905.[a]

[Drainage area, 9,650 square miles.]

Year.	Date.	Gage height.	Discharge.
		Feet.	*Sec.-feet.*
1877		(b)	
1889	June 2		[c] 470,000
1895	March 3	10.6	65,980
1896	September 30	5.3	25,380
	October 1	21.9	159,800
	October 2	12.1	78,430
1897	February 22	6.7	34,900
	February 23	21.2	154,000
	February 24	24.6	182,200
	February 25	16.8	117,400
	May 3	6.5	33,480
	May 4	14.0	94,200
	May 5	8.5	48,700
	May 14	8.9	51,900
	May 15	12.6	82,580
	May 16	8.0	44,720
1898	August 10	5.6	27,340
	August 11	14.0	94,200
	August 12	16.1	111,600
	August 13	9.5	56,850
	October 22	5.4	26,020
	October 23	13.1	86,730
	October 24	10.1	61,830
1899	February 22	8.5	48,700
	February 23	14.8	100,800
	February 24	13.7	91,710
	February 25	9.0	52,700
	February 27	9.3	55,190
	February 28	13.9	93,370
	March 1	11.9	76,770
	March 2	9.2	54,360
	March 5	8.5	48,700
	March 6	16.6	115,800
	March 7	12.9	85,070
	March 8	10.0	61,000
1901	March 11	4.2	18,680
	March 12	12.4	80,920
	March 13	9.9	60,170
	April 15	9.0	52,700
	April 16	15.0	102,500
	April 17	8.3	47,100
	April 20	5.4	26,020
	April 21	11.4	72,620
	April 22	20.8	150,600
	April 23	15.8	109,100
	April 24	11.2	70,960
	April 25	7.9	43,940
	May 22	1.9	
1901	May 23	12.6	82,580
	May 24	14.2	95,860
	May 25	9.3	55,190
	December 15	8.1	45,500
	December 16	17.2	120,800
	December 17	13.3	88,390
	December 18	6.9	36,340
	December 29	4.4	19,840
	December 30	13.8	92,540
	December 31	18.4	130,700
1902	January 1	11.7	75,110
	February 25	4.4	19,840
	February 26	17.8	125,700
	February 27	27.2	203,800
	February 28	18.0	127,400
	March 1	22.5	164,800
	March 2	29.0	218,700
	March 3	16.1	111,600
	March 4	10.2	62,660
	March 11	12.0	77,600
	March 12	12.4	80,920
	March 13	14.0	94,200
	March 14	13.8	92,540
	March 15	12.0	77,600
	March 16	10.2	62,660
	April 8	6.4	28,780
	April 9	16.4	108,700
	April 10	14.3	91,290
	April 11	12.9	79,670
	April 12	12.2	73,800
	April 13	11.5	68,050
1903	February 28	5.4	22,300
	March 1	14.2	90,460
	March 2	15.3	99,590
	March 3	8.9	46,820
	March 24	7.0	32,820
	March 25	12.1	73,030
	March 26	8.6	44,500
	April 14	5.6	23,560
	April 15	14.4	92,120
	April 16	15.1	97,930
	April 17	14.0	88,800
	April 18	10.4	58,920
1905	March 10	6.4	28,780
	March 11	11.0	63,900
	March 12	10.1	56,430
	March 13	6.9	32,140

[a] Description of this station is given in Water-Sup. and Irr. Paper U. S. Geol. Survey No. 167, p. 55.
[b] See Rept. Chief of Engrs. U. S. Army, 1881, p. 940, for comparisons of floods of 1877 and 1881.
[c] Discharge at Chain Bridge.

The largest flood, except for that of 1889, in the lower part of this basin occurred in February, 1881, and was due to an ice gorge.[a] The stage at Long Bridge, Washington, D. C., was 2.5 feet greater than during the flood of 1877. About 254 acres of the city of Washington was submerged during this flood.

On June 2, 1889, occurred the largest flood on this stream. Above Harpers Ferry [b] it reached a stage of 34 feet above low water and 6.8 feet above that attained during the flood of 1877. The mean rate of flow June 2 at Chain Bridge, Washington, was 40.9 second-feet per square mile from 11,500 square miles of area.

The storm [c] causing this flood extended from Kansas to the Atlantic and from the Great Lakes to the Carolinas. It caused unprecedented floods in the Susquehanna River basin, and to it was due the great disaster at Johnstown, Pa.

The largest flood since 1889 was on March 2, 1902, when the discharge was 218,700 second-feet at Point of Rocks.

CAPE FEAR RIVER.

Cape Fear River is formed by the junction of New and Deep rivers in Chatham County, N. C., flows 192 miles in a general southeasterly direction, and empties into the Atlantic Ocean. Steamers of light draft ascend the river to Fayetteville, a distance by river of 160 miles. From Fayetteville up to Smileys Falls, a distance of 25 miles, the fall is only 1.25 feet per mile.

The basin above Fayetteville is long and narrow and has an area of 3,860 square miles. It is gently rolling or hilly, with thin soil that absorbs moisture slowly. The run-off into the main channel is therefore large and rapid and the floods on this stream are more violent than those on any other stream in North Carolina.

The following table gives the stages of this stream at Fayetteville during all the large floods from 1889 to 1902 and the approximate daily discharge during some of them:

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[a] Rept. Chief of Engrs. U. S. Army, 1881, p. 940.
[b] Rept. Chief of Engrs. U. S. Army, 1889, p. 985.
[c] Eng. News, vol. 21, p. 528.

Flood flow of Cape Fear River at Fayetteville, N. C., 1889-1904.[a]

[Drainage area, 3,860 square miles. Danger line, 38 feet gage height.]

Year.	Date.	Gage height.[b]	Discharge.	Year.	Date.	Gage height.[b]	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1889	February 20	43.0		1895	April 10	47.7	
	June 1	10.0			May 1	44.6	
	June 2	40.0		1896	February 8	48.0	
	June 3	30.0			July 11	49.5	
	July 3	43.9		1899	February 9	52.0	
	July 23	45.0	53,000 to 58,000		February 20	43.0	
					March 17	42.0	
	August 1	44.2		1900	April 21	44.0	
1891	March 14	41.0			April 22	44.0	
	May 30	45.1		1901	April 5	47.7	
	August 24	43.1			May 22	14.0	
1892	January 21	49.5	55,000 to 65,000		May 23	48.0	
1893	February 15	42.3			May 24	58.5	70,000 to 90,000
	October 24	42.0			May 25	54.7	
1894	October 12	47.9			May 26	42.0	
1895	January 10	37.0			May 27	33.9	
	January 11	52.0			July 15	41.5	
	January 12	58.0	70,000 to 90,000		August 15	42.0	
					September 20	43.6	
	January 13	56.0		1902	February 4	40.3	
	January 14	47.4			March 2	41.7	
	January 15	38.0		1903	March 25	50.5	55,000 to 65,000
	March 22	41.0					

[a] A description of this gaging station is given in Water-Sup. and Irr. Paper U. S. Geol. Survey No. 83, p. 31.
[b] U. S. Weather Bureau gage records.

NOTE.—The lowest stage was 0.7 foot on the gage October 5, 1895, and the flow was 0.069 second-foot per square mile.

The largest flood during this period occurred in May, 1901, and reached a stage of 58.5 feet, or about 58 feet above low water. The discharge is estimated to have been from 70,000 to 90,000 second-feet, or from 18 to 23 second-feet per square mile. High stages occur often in this stream, and in nearly all months of the year. The rise and fall are very rapid. The very great range of stage at this place is due to the small slope of the stream bed and the small channel, which is U-shaped, with high banks and small bottom width. At the junction of New and Deep rivers, where the slope and width are greater than at Fayetteville, the range of stage is about 25 feet. It is reported that the stage at Fayetteville has been 75 feet.

SAVANNAH RIVER.

Savannah River is formed by the junction of Tugaloo and Seneca rivers in the northern part of North Carolina, about 100 miles north of Augusta, flows in a southerly direction a distance of 355 miles by river, and empties into the Atlantic Ocean at Savannah The stream is navigable to Augusta, a distance by river of 248 miles. The fall in this distance is above 130 feet. From Augusta to Andersonville, a distance of 107 miles, the fall is 270 feet. The basin is long and narrow and comprises a drainage area above Augusta of 7,500 square miles. The upper part extends well up into the Blue Ridge Mountains and has a

rapid run-off. Numerous comparatively small streams enter the main stream at considerable distances apart. This stream is subject to large freshets, due to rain and the rapid melting of snow in the mountains in the spring. The greatest flood, however, occurred in September, and was due to rain alone.

The following table gives the daily rate of flow of this stream at Augusta, Ga., during all the large floods from 1840 to 1905:

Flood discharge of Savannah River at Augusta, Ga., 1840–1905.[a]

[Drainage area, 7,500 square miles. Danger line, 32 feet. Lowest stage, 2.5 feet.]

Year.	Date.	Gage height.[b]	Discharge.	Year.	Date.	Gage height.[b]	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1840	May 28	37.8	[c]253,000	1888	September 12	33.9	138,300
1852	August 29	36.8	[c]220,000		September 13	23.2	47,560
1865	January 11	36.4	[c]202,000	1889	February 18	30.6	109,300
1878	July 31	34.5	[c]143,000		February 19	32.9	129,500
1888	September 11	38.7	[c]300,000		February 20	29.3	97,840
1881	March 17	28.5	90,800	1891	March 9	31.2	114,600
	March 18	32.2	123,360		March 10	35.3	165,400
	March 19	23.3	47,660		March 11	32.6	126,900
1886	March 31	30.8	111,040		March 12	27.7	83,760
	April 1	32.2	123,360		March 13	31.2	114,600
	April 2	29.0	95,200		March 14	29.5	99,600
	May 20	28.7	92,560	1892	January 20	31.0	112,800
	May 21	32.5	126,000		January 21	32.5	126,000
	May 22	26.8	75,840		January 22	26.8	75,840
1887	July 29	14.0	17,900	1896	July 9	29.2	96,960
	July 30	32.3	124,200			30.2	105,800
	July 31	34.5	143,600			25.8	67,040
	August 1	32.0	121,600	1899	February 7	28.0	86,400
	August 2	28.1	87,280		February 8	31.0	112,800
	August 3	31.7	119,000		February 9	29.9	103,100
	August 4	32.1	122,500	1900	February 13	29.6	100,500
	August 5	23.9	51,380		February 14	32.3	124,200
	August 9	30.8	111,000		February 15	22.1	41,480
	August 10	33.0	130,400	1902	February 28	25.5	64,400
	August 11	24.0	52,000		March 1	33.8	137,400
1888	March 29	30.6	109,300		March 2	33.3	133,000
	March 30	32.7	127,800		March 3	28.6	91,680
	March 31	29.8	102,200	1903	February 8	30.7	110,200
	September 9	23.5	48,900		February 9	33.0	130,400
	September 10	34.7	148,600		February 10	28.7	92,560
	September 11	38.1	276,500	1905	February 14	25.3	62,700

[a] Description of station in Water-Sup. and Irr. Paper U. S. Geol. Survey No. 98, p. 57.
[b] Property of city of Augusta, Ga.
[c] House Document No. 213, 51st Cong., 1st sess.

The largest flood at this place during the period covered by the table occurred September 11, 1888.[a] The maximum stage was 38.7 feet and the maximum rate of flow was 40 second-feet per square mile. The normal rainfall for September at Augusta is 2 to 4 inches. The rainfall for September, 1888, was 12 inches. The water was from 1 foot to 12 feet deep over a part of the city of Augusta, and the flood did a large amount of damage.

Second in size was the flood of 1840, during which the maximum rate of flow was 33.7 second-feet per square mile.

[a] Report on survey of the Savannah River above Augusta, Ga., House Doc. 213, 51st Cong., 1st sess.

ALABAMA RIVER.

Alabama River is formed by the junction of the Coosa and Tallapoosa rivers 6 miles above Montgomery, Ala. The drainage basin of these streams is hilly country, well wooded, and about one-fourth of the land is under cultivation. The streams have comparatively little fall, a sluggish flow, and are subject to great fluctuations of stage. The channel is deep and the area flooded comparatively small for such extreme fluctuations of stage.

The following table gives the daily rate of flow of the Alabama at Selma, Ala., of the large floods from 1891 to 1904:

Flood flow of Alabama River at Selma, Ala., 1891 to 1904. [a]

[Drainage area, 15,400 square miles. Lowest water −1.9 feet, November 9, 1894. Danger line, 35 feet.]

Year.	Date.	Gage height.[b]	Discharge.	Year.	Date.	Gage height.[b]	Discharge.
		Feet.	*Sec. feet.*			*Feet.*	*Sec. feet.*
1891	March 13	47.3	127,260	1900	February 17	48.0	129,200
	March 14	48.0	129,200		February 18	47.9	128,900
	March 15	47.6	128,100		April 23	41.0	110,000
1892	January 16	50.3	135,500		April 24	40.0	107,200
	January 17	52.2	140,800	1901	January 17	40.0	107,200
	January 18	53.8	145,200		April 23	39.0	104,400
	January 19	54.0	145,700	1902	January 2	45.0	121,000
	January 20	53.7	144,900		January 3	46.6	125,400
	January 21	52.8	142,400		January 4	46.3	124,500
	January 22	52.4	141,300		March 4	47.1	126,700
	January 23	52.1	140,500		March 5	47.1	126,700
	January 24	52.1	140,500		March 6	46.2	124,200
	January 25	51.3	138,300		March 7	44.4	119,300
	March 29	48.3	130,000		March 31	48.9	131,700
	March 30	48.5	130,600		April 1	50.1	135,000
	April 14	46.0	123,700		April 2	50.7	136,600
1893	February 20	44.0	118,200		April 3	50.0	134,700
	February 21	44.6	119,800		April 4	48.6	130,800
	February 22	43.9	117,900	1903	February 12	48.0	129,200
1895	March 19	41.8	112,200		February 13	49.5	133,300
	March 20	42.6	114,400		February 14	50.2	135,200
	March 22	41.8	112,200		February 15	50.6	136,400
1897	March 17	40.7	109,200		February 16	49.9	134,400
1899	March 3	38.8	103,900		February 17	49.0	132,000

[a] For description of station, see Water-Sup. and Irr. Paper No. 83, p. 131.
[b] U. S. Weather Bureau records.

The largest flood during this period occurred in January, 1892. The stream was nearly 56 feet above low water and the maximum rate of flow was 145,700 second-feet, or 9.5 second-feet per square mile. High stages occur nearly every year and last from one or two weeks to a month. The flood flow is comparatively small and these high stages are due to narrow channel and small slope of stream bed.

BLACK WARRIOR RIVER.

Black Warrior River is formed by the junction of the Mulberry and Sipsey forks at Warriortown, Ga., flows in a southerly direction and empties into the Tombigbee. The basin is rolling or flat open country, much of which is under cultivation. The stream has little fall and its flow is sluggish. The area above the gaging station at Tuscaloosa, Ala., is 4,900 square miles.

The following table gives the daily flow at this station during the large floods from 1889 to 1905:

Flood flow of Black Warrior River at Tuscaloosa, Ala., 1889–1905. [a]

[Drainage area, 4,900 square miles. Danger line, 43.0 feet gage height. Lowest stage, — 0.8 foot.]

Year.	Date.	Gage height.[b]	Discharge.	Year.	Date.	Gage height.[b]	Discharge.
		Feet.	Sec. feet.			Feet.	Sec. feet.
1889	January 18	40.5	63,000	1895	March 17	52.0	109,000
	February 18	56.4	126,600		March 18	47.3	90,200
	February 19	56.6	127,400		March 22	51.3	106,200
	February 20	53.0	113,000	1897	March 7	51.4	106,600
1890	February 9	54.0	117,000		March 8	54.8	120,200
	February 10	52.9	112,600		March 9	51.6	107,400
	March 1	58.9	136,600		March 14	51.0	105,000
	March 2	57.4	130,400	1898	January 27	43.5	75,000
	March 3	52.4	110,600		April 6	38.7	55,800
	April 5	45.9	....	1899	January 8	49.3	98,200
1891	February 8	51.5	107,000		February 6	50.6	103,400
	February 9	51.5	107,000		February 7	51.4	106,400
	February 10	52.2	109,800		February 8	51.7	107,800
	February 11	53.5	115,000		February 9	48.6	95,400
	February 12	50.5	103,000		March 16	59.3	138,200
	February 13	47.6	91,400		March 17	60.3	142,200
	February 14	51.4	106,600		March 18	57.7	131,800
	February 15	49.5	99,000		March 19	52.4	110,600
	March 7	53.0	113,000		March 20	49.3	98,200
	March 8	58.0	133,000		December 13	39.5	59,000
	March 9	60.4	142,600	1900	February 14	48.0	93,000
	March 10	58.0	133,000		March 21	51.0	105,000
	March 11	54.0	117,000		April 12	52.8	112,200
1892	January 13	53.0	113,000		April 13	53.4	114,600
	January 14	57.4	130,600		April 14	48.7	95,800
	January 15	55.9	124,600		April 17	63.0	153,000
	January 16	51.7	107,800		April 18	64.0	157,000
	April 6	11.6	....		April 19	62.2	149,800
	April 7	56.3	126,200		April 20	59.4	138,600
	April 8	63.2	153,800		April 21	56.1	125,400
	April 9	62.2	149,800		April 22	51.7	107,800
	April 10	58.0	133,000		April 23	46.2	85,800
	April 11	52.3	110,200		June 24	50.0	101,000
	April 12	45.4	....		June 25	58.4	134,600
	April 13	40.7	....		June 26	56.4	126,600
	April 14	36.5	....		June 27	52.9	112,600
	July 11	46.2	85,800		June 28	49.1	97,400
1893	February 16	52.2	109,800	1901	January 12	52.7	111,800
	February 17	55.6	123,400		January 13	56.5	127,000
	February 18	54.7	119,800		January 14	53.3	114,200
	February 19	51.4	106,600		January 15	47.3	90,200
	May 4	51.2	105,800		February 5	42.0	69,000
	May 5	52.2	109,800		April 21	42.6	71,400
	May 6	48.0	93,000		December 30	49.0	97,000
	June 3	49.6	99,400		December 31	49.0	97,000
	June 4	46.0	85,000	1902	January 1	44.0	77,000
1895	January 9	50.6	103,400		February 3	48.4	94,600
	January 10	49.3	98,200		March 1	49.9	100,600

[a] Description of station in Water-Sup. and Irr. Paper No. 98, p. 159.
[b] U. S. Army Engineers records.

Flood flow of Black Warrior River at Tuscaloosa, Ala., 1889–1905—Continued.

Year.	Date.	Gage height.	Discharge.	Year.	Date.	Gage height.	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1902	March 28	60.4	142,600	1903	February 17	56.7	127,800
	March 29	60.6	143,400		February 18	56.8	128,200
	March 30	58.3	134,200		February 19	53.0	113,000
	March 31	57.4	130,600		March 1	54.3	118,200
	April 1	52.9	112,600		May 16	43.4	74,600
1903	February 8	56.4	126,600	1905	January 14	46.1	85,400
	February 9	55.9	124,600		February 9	55.5	123,000
	February 10	51.5	107,000		February 10	56.9	128,000
	February 11	52.0	109,000		February 11	54.5	119,000
	February 12	53.8	116,200		February 22	47.7	91,800
	February 13	51.1	105,400				

The largest flood during this period was in April, 1900. The stage on the 18th was 64 feet, or about 64.8 feet above low water. The maximum daily rate was 157,000 second-feet, or 32 second-feet per square mile. This great range of stage is due to sluggish flow and narrow, deep channel. They last from one to three or four weeks.

It is reported that the stage at this place has been 87.6 feet.

MONONGAHELA RIVER.

The Monongahela rises in the north-central part of West Virginia, flows in a general northerly direction, and joins the Allegheny at Pittsburg to form the Ohio (see Pl. IV). Its principal tributaries are the Cheat, which enters from the east a few miles north of the southern boundary of Pennsylvania, and the Youghiogheny, which enters from the east at McKeesport. The basin of the Monongahela has an area of 7,625 square miles, embracing the west slope of the Allegheny Mountains. It is mainly mountainous or hilly, with no surface storage and little forest area, and stands at a higher elevation than the Ohio basin, immediately west of it. From Fairmount to the mouth of the stream, a distance of 123 miles, the fall of the river is about 1.1 feet per mile. This part of the stream consists of a series of slack-water basins formed by dams.

The following table gives the daily rate of flow of the Monongahela at Lock No. 4 during all the large floods from 1886 to 1905:

Flood flow of the Monongahela River at Lock No. 4, Pennsylvania, 1886–1905.

[Drainage area, 5,430 square miles. Lowest stage, 3.2 feet. Danger line, 28 feet.]

Year.	Date.	Gage height.[a]	Discharge.	Year.	Date.	Gage height.[a]	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1886	March 31	16.5	33,600	1886	May 12	10.2	....
	April 1	27.0	92,600		May 13	15.3	28,150
	April 2	23.5	70,800		May 14	21.2	57,900
	April 3	16.0	31,300		May 15	24.3	75,600
	April 5	18.5	43,600		May 16	16.5	33,600
	April 6	25.0	79,800	1887	February 3	14.0	22,500
	April 7	26.0	85,800		February 4	31.0	120,600
	April 8	19.5	48,600		February 5	24.5	76,800
	May 8	6.5	....		February 6	16.3	32,650
	May 9	22.0	62,300		February 26	11.7	14,500
	May 10	16.5	33,600		February 27	28.0	99,600
	May 11	11.5	....		February 28	24.0	73,800

[a] U. S. Weather Bureau records.

Flood flow of the Monongahela River at Lock No. 4, Pennsylvania, 1886–1905—Continued.

Year.	Date.	Gage height.	Discharge.	Year.	Date.	Gage height.	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1887	March 1	16.3	32,650	1891	February 22	19.0	46,100
1888	January 8	19.5	48,600		February 23	20.4	53,500
	January 9	20.7	55,150		February 24	15.3	28,150
	January 10	16.5	33,600	1892	January 13	11.0	....
	July 9	6.9	....		January 14	25.7	84,000
	July 10	26.0	85,800		January 15	28.5	103,100
	July 11	42.0	207,000		January 16	19.3	47,600
	July 12	27.0	92,600		April 23	18.0	41,100
	July 13	14.5	....		April 24	21.6	60,100
1889	February 17	12.7	17,490		April 25	15.5	29,050
	February 18	27.0	92,600	1893	January 29	16.5	33,600
	February 19	25.5	82,800		January 30	23.5	70,800
	February 20	19.5	48,600		January 31	18.2	42,100
	April 13	13.0	18,540	1895	January 6	7.3	....
	April 14	21.0	56,800		January 7	24.5	76,800
	April 15	17.7	39,600		January 8	30.0	113,600
	May 31	8.7	....		January 9	22.0	62,300
	June 1	25.0	79,800		January 10	15.8	30,400
	June 2	19.4	48,100		January 11	21.9	61,750
	November 9	11.9	15,000		January 12	19.0	46,100
	November 10	21.4	59,000		March 15	14.5	24,600
	November 11	18.0	41,100		March 16	21.0	56,800
1890	January 7	10.0	....		March 17	21.7	60,650
	January 8	20.5	54,050		March 18	16.4	33,100
	January 9	20.0	51,300	1896	March 19	11.2	....
	January 10	16.4	33,100		March 20	20.5	54,050
	February 3	10.8	....		March 21	18.6	44,100
	February 4	•21.1	57,350		July 30	14.2	23,340
	February 5	21.1	57,350		July 31	25.3	81,600
	February 6	16.2	32,200		August 1	24.0	73,800
	February 20	11.0	....		August 2	15.6	29,500
	February 21	23.5	70,800	1897	February 22	16.0	31,300
	February 22	19.5	48,600		February 23	36.0	159,000
	March 22	19.5	48,600		February 24	36.0	159,000
	March 23	31.8	126,200		February 25	23.0	67,800
	March 24	28.5	103,100		February 26	14.0	22,500
	March 25	18.8	45,100		May 14	19.7	49,650
	October 12	11.8	14,800		May 15	20.6	54,600
	October 13	20.1	51,850		May 16	14.6	25,040
	October 14	24.3	75,600		December 5	8.0	....
	October 15	21.5	59,550		December 6	20.6	54,600
	October 16	15.0	26,800		December 7	15.6	29,500
1891	January 1	9.0	....	1898	January 10	14.0	22,500
	January 2	27.0	92,600		January 11	23.9	73,200
	January 3	31.3	122,700		January 12	20.0	51,300
	January 4	20.8	55,700		January 13	15.8	30,400
	January 5	14.1	22,920		January 16	19.5	48,600
	February 10	17.0	36,100		January 17	21.0	56,800
	February 11	24.0	73,800		January 18	16.0	31,300
	February 12	18.8	45,100		January 23	13.5	20,480
	February 16	12.3	16,210		January 24	21.9	61,750
	February 17	21.8	61,200		January 25	16.7	34,600
	February 18	20.5	54,050		March 17	8.5	....
	February 19	16.3	32,650		March 18	20.0	51,300

Flood flow of the Monongahela River at Lock No. 4, Pennsylvania, 1886–1905—Continued.

Year.	Date.	Gage height.	Discharge.	Year.	Date.	Gage height.	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1898	March 19	16.7	34,600	1901	May 28	21.3	58,450
	March 20	12.7	....		May 29	20.0	51,300
	March 21	13.8	21,680		May 30	17.1	36,600
	March 22	22.5	65,050		December 15	18.5	43,600
	March 23	20.7	55,150		December 16	28.5	103,100
	March 24	20.2	52,400		December 17	18.5	43,600
	March 25	24.7	78,000		December 29	16.5	33,600
	March 26	23.8	72,600		December 30	25.0	79,800
	March 27	16.0	31,300		December 31	22.0	62,300
	March 28	12.5	....	1902	January 27	9.5	....
	March 29	12.0	15,300		January 28	25.9	85,200
	March 30	23.9	73,200		January 29	19.5	48,600
	March 31	20.7	55,150		February 26	16.4	33,100
	April 1	14.5	24,600		February 27	21.5	59,550
	August 10	17.3	37,600		February 28	18.8	45,100
	August 11	23.3	69,600		March 1	29.5	110,100
	August 12	21.0	56,800		March 2	25.1	80,400
	August 13	17.8	40,100		March 3	20.0	51,300
	October 22	14.0	22,500		March 4	15.6	29,500
	October 23	21.6	60,100		March 9	11.3	....
	October 24	15.8	30,400		March 10	21.6	60,100
1899	January 6	15.0	26,800		March 11	19.6	49,100
	January 7	23.5	70,800		April 9	17.2	37,100
	January 8	23.0	67,800		April 10	20.1	51,850
	January 9	15.6	29,500		April 11	22.0	62,300
	February 4	11.5	....		April 12	22.7	66,150
	February 5	22.0	62,300		April 13	21.5	59,550
	February 6	17.5	38,600		April 14	17.7	39,600
	March 5	14.0	22,500		December 12	20.0	51,300
	March 6	26.9	91,900		December 13	25.0	79,800
	March 7	20.0	51,300		December 14	26.2	87,000
	March 28	9.5	....		December 15	19.0	46,100
	March 29	23.0	67,800		December 16	17.0	36,100
	March 30	23.0	67,800		December 17	26.0	85,800
	March 31	16.5	33,600		December 18	20.5	54,050
1900	March 1	10.2	....		December 19	14.5	24,600
	March 2	21.0	56,800	1903	January 3	10.9	....
	March 3	19.0	46,100		January 4	22.1	62,850
	November 26	17.6	39,100		January 5	18.9	45,600
	November 27	33.8	141,400		February 4	16.0	31,300
	November 28	22.6	65,600		February 5	21.7	60,650
	November 29	14.8	25,920		February 6	17.8	40,100
1901	April 4	18.8	45,100		February 15	10.5	....
	April 5	21.6	60,100		February 16	22.6	65,600
	April 6	20.6	54,600		February 17	28.4	102,400
	April 7	23.1	68,400		February 18	19.2	47,100
	April 8	21.6	60,100		February 28	14.6	25,040
	April 9	17.0	36,100		March 1	32.5	131,100
	April 19	12.0	15,300		March 2	24.6	77,400
	April 20	23.3	69,600		March 3	15.7	29,950
	April 21	25.5	82,800		March 23	13.0	18,540
	April 22	21.5	59,550		March 24	23.2	69,000
	April 23	17.2	37,100		March 25	21.0	56,800
	May 27	19.4	48,100		March 26	14.6	25,040


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Flood flow of the Monongahela River at Lock No. 4, Pennsylvania, 1886–1905—Continued.

Year.	Date.	Gage height.	Discharge.	Year.	Date.	Gage height.	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1904	January 22	13.8	21,680	1905	March 8	12.0	15,300
	January 23	21.2	57,900		March 9	21.0	56,800
	January 24	20.0	51,300		March 10	28.3	101,700
	January 25	14.5	24,600		March 11	29.3	108,700
	March 23	14.2	23,340		March 12	18.5	43,600
	March 24	20.2	52,400		March 21	16.5	33,600
	March 25	16.8	35,100		March 22	27.2	94,000
1905	January 11	10.2	....		March 23	20.5	54,050
	January 12	24.3	75,600		March 24	13.4	20,080
	January 13	19.5	48,600				

The discharge is taken from a station rating table prepared from current-meter measurements of the flow at Belle Vernon, Pa., and surface slope data furnished by T. P. Roberts, Corps of Engineers, United States Army.

The gage is located at the lower end of the lock below the dam; its zero is 717.82 feet above sea level.

The greatest rate of discharge during this period was on July 11, 1888. The stream reached a stage of 42 feet, 38.8 feet above lowest stage, and a daily rate of flow of 207,000 second-feet, or 38.1 second-feet per square mile. Both the rise and fall during this flood were very rapid. It was due to a very heavy rain of comparatively short duration.

The flood second in size occurred February 23–24, 1897, when a stage of 36 feet was reached, and a rate of 159,000 second-feet, or 29.3 second-feet per square mile. It was a spring flood, due to rain and the rapid melting of snow.

YOUGHIOGHENY RIVER.

The Youghiogheny, the chief tributary of the Monongahela, drains an area of about 1,770 square miles. It rises in the mountains about 30 miles south of the Pennsylvania-West Virginia line, flows northwestward about 85 miles, and enters the Monongahela at McKeesport, Pa. Its chief tributary is the Casselman, which enters from the east, at Confluence, Pa. The basin is mountainous and quick spilling, without storage. The stream bed is steep and rocky and the flow rapid.

The following table gives the daily flow just below the mouth of the Casselman at Confluence, Pa., of all the large floods from 1874 to 1905:

Flood flow of Youghiogheny River at Confluence, Pa., 1874-1905.[a]

[Drainage area, 782 square miles. Lowest stage, −0.8 foot. Danger line, 10 feet.]

Year.	Date.	Gage height.	Discharge.	Year.	Date.	Gage height.	Discharge.
		Feet.	*Second-feet.*			*Feet.*	*Second-feet.*
1874	December 28	8.5	17,320	1891	February 16	6.9	
	December 29	13.2	30,420		February 17	12.3	27,720
	December 30	6.1			February 18	10.2	21,750
1875	July 28	3.0			February 19	6.9	
	July 29	10.7	23,100	1895	January 7	8.5	17,320
	July 30	5.2			January 8	10.8	23,370
	August 1	5.4			January 9	7.3	
	August 2	12.3	27,720	1896	March 29	7.6	
	August 3	10.3	22,020		March 30	10.5	22,560
	August 4	6.8			March 31	8.9	18,340
1876	September 17	4.4			July 24	5.4	
	September 18	11.6	25,630		July 25	13.0	29,820
	September 19	7.6			July 26	5.9	
1877	November 23	2.2		1897	February 21	5.8	
	November 24	11.6	25,630		February 22	11.6	25,630
	November 25	7.8			February 23	13.0	29,820
1881	February 11	9.6	20,170		February 24	9.6	20,170
	February 12	11.6	25,630	1900	November 25	3.3	
	February 13	9.4	19,640		November 26	10.3	22,020
1882	February 20	8.4	17,060		November 27	7.3	
	February 21	10.5	22,560	1901	April 6	7.6	
	February 22	8.3	16,810		April 7	10.5	22,560
1883	February 6	3.6			April 8	8.0	16,060
	February 7	13.8	32,220		December 14	2.6	
	February 8	9.2	19,120		December 15	10.6	22,830
1888	August 21	17.0	42,000		December 16	7.0	
			to 46,000	1902	February 27	4.0	
1889	May 31	9.6	20,170		February 28	9.9	21,470
	June 1	12.0	26,820		March 1	10.1	20,960
	June 2	6.1		1904	January 22	9.0	18,600
1890	March 22	9.0	18,600		January 23	10.6	22,830
	March 23	10.9	23,650		January 24	5.0	
	March 24	7.6		1905	March 21	8.0	16,060

[a] Gage heights from U. S. Weather Bureau records.

The largest flood on this stream in these thirty-one years occurred in August, 1888. The maximum rate of flow was then from 42,000 to 46,000 second-feet, or from 53.8 to 59 second-feet per square mile. Second in size to this flood was the spring flood of February 1883, when the maximum daily rate of flow was 41.2 second-feet per square mile.

TENNESSEE RIVER.

Tennessee River is formed by the junction of the French Broad and the Holston about 4 miles above Knoxville, Tenn. It is a long, somewhat U-shaped stream and is navigable to Chattanooga, a distance of 453 miles. The basin above Chattanooga is mountainous, being made up of a series of parallel ridges. The tributary streams drain the narrow valleys between these ranges. There is no surface and little ground storage, and the run-off is therefore very rapid.

The drainage area above Chattanooga, where the gaging station is located, is 21,380 square miles. The following table gives the daily rate of flow of this stream at Chattanooga during all the larger floods from 1867 to 1905.

Flood flow of Tennessee River at Chattanooga, Tenn., 1867–1905.[a]

[Drainage area, 21,382 square miles. Danger line, 33 feet gage height. Lowest stage, 0.0.]

Year.	Date.	Gage height.[b]	Discharge.	Year.	Date.	Gage height.[b]	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1867	March 11	58.0	[c]735,000	1897	March 14	37.9	363,200
1890	February 28	34.8	308,100		March 15	37.9	363,200
	March 1	40.2	404,200		March 16	37.0	347,200
	March 2	42.5	445,100		March 17	36.0	329,400
	March 3	41.0	418,400	1899	February 8	36.95	225,100
	March 4	34.4	300,900		February 9	38.25	333,200
1891	February 12	34.3	299,200		February 10	36.75	223,800
	February 13	36.5	338,300		March 17	36.90	224,800
	February 14	37.5	356,100		March 18	36.15	220,200
	February 15	35.5	320,500		March 19	35.85	218,300
	March 10	37.5	356,100		March 20	37.05	225,700
	March 11	38.9	381,000		March 21	39.20	239,000
	March 12	37.6	357,900		March 22	40.00	244,000
1892	January 16	37.1	349,000		March 23	38.70	235,900
	January 17	37.9	363,200		March 24	32.70	198,700
	January 18	35.2	315,200	1901	December 30	32.00	202,200
	April 10	34.3	299,200		December 31	37.40	237,300
1893	February 20	33.4	283,200	1902	January 1	40.10	254,800
1896	April 4	38.8	379,300		January 2	40.80	259,400
	April 5	40.5	409,500		March 4	38.0	241,200
1897	February 26	34.8	308,100		March 5	35.9	227,600

[a] Description of station given in Water-Sup. and Irr. Paper No. 98, p. 255.
[b] U. S. Weather Bureau records.
[c] Two per cent added for overflow passing around gage.

The flood of March, 1867, on this river exceeded all floods in the preceding ninety[a] years. It was one great rise, due to a very great storm that extended over the whole drainage area. At noon on March 11 the stage was 58 feet above low water at Chattanooga. At Knoxville the stage was 12 feet above that of 1847. The loss of life and property in this valley was unparalleled.

Second in size was the flood from February 27 to March 5, 1890, which had a maximum rate on March 2 of 445,120 second-feet, or about 0.6 the rate of the flood of March, 1867.

ILLINOIS RIVER.

Illinois River is the largest tributary of the Mississippi above the Missouri. It is formed by the junction of the Kankakee and Desplaines rivers in northeast Illinois. The basin including these streams has an area of 29,013 square miles, and its width is about half its length. It is level or gently undulating land, with a deep, rich, loamy soil, and is nearly all under cultivation. From Lake Michigan to Lasalle the fall of the river is 141 feet, and from Lasalle to its mouth the fall is 33 feet. The Chicago Drainage Canal extends from Lake Michigan to Illinois River at Joliet, and through it passes into the river 3,000 to 5,000 second-feet of the water of Lake Michigan. A large part of the Kankakee River basin in Indiana is a swamp formed by a ledge of limestone crossing the valley near the State line. This swamp exerts a marked influence on the flood flow and also on the low-water flow of the river.

[a] Rept. Chief Engr. U. S. Army for 1875, p. 635.

The following table gives the daily rate of flow of Illinois River at Peoria, Ill., during larger floods from 1890 to 1905. The gage heights are readings of the United States Weather Bureau gage on a pile of the protecting work of pier of the Peoria wagon bridge.

Flood flow of Illinois River, Peoria, Ill., 1890 to 1905.[a]

[Drainage area, 15,700 square miles. Danger line, 14 feet. Lowest water, 2.6 feet.]

Year.	Date.	Gage height.[b]	Discharge.	Year.	Date.	Gage height.[b]	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1890	June 25	13.3	18,290	1899	March 22	15.1	23,330
1891	April 17	15.0	22,960	1900	March 16	19.9	43,560
	April 18	15.0	22,960		March 17	19.9	43,560
	April 19	15.0	22,960	1901	March 27	17.0	30,900
1892	May 6	18.9	39,120		March 28	17.2	31,760
	May 7	20.9	47,920		March 29	17.4	32,620
	May 8	21.5	50,480		March 30	17.6	33,480
	May 9	21.9	52,180		March 31	17.7	33,910
	May 10	21.3	49,620		April 1	17.6	33,480
	May 11	20.7	47,140		April 2	17.5	33,050
	May 12	20.0	44,000	1902	July 22	21.0	48,350
	May 13	19.9	43,560	1903	March 12	19.3	40,880
	May 14	19.4	41,330		March 12	19.3	40,880
1893	March 13	19.6	42,220	1904	March 28	[c][d] 21.8	57,500
1895	December 31	15.0	22,960	1905	March 8	[d] 15.0	24,090
1897	March 24	18.3	36,500		May 19	[d] 17.4	35,500
1898	March 31	19.3	40,880				

[a] Description of gaging station in Water-Sup. and Irr. Paper No. 128, p. 39.
[b] Heights on U. S. Weather Bureau gage.
[c] From March 24 to April 7 this stage was above 20 feet, and from January 22 to May 19 the stage did not fall below 13 feet.
[d] Heights on U. S. Geological Survey gage.

The largest flood on this stream in these sixteen years occurred March, 1904. The greatest stage was 21.8 feet, or 19.2 feet above low water, and the greatest rate of flow was 57,500 second-feet, or 3.66 second-feet per square mile. For fifteen days during this flood the discharge did not fall below 44,000 second-feet.

Second in size was the flood of May, 1902, which had a maximum rate of 3.3 second-feet per square mile.

The floods on this stream are of long duration, but have a very small rate of flow.

MISSISSIPPI RIVER.

The Mississippi has its source in Itaska Lake, in northern Minnesota, at an elevation of 1,324 feet above sea level. From this lake to St. Paul, Minn., a distance of about 500 miles, it falls about 1,000 feet. The watershed is mostly hilly, without mountains, with considerable swampy land and lake surface. The surface covering is drift composed of sand, gravel, and bowlders. The total area above St. Paul is 36,085 square miles, 16,350 square miles of which is Minnesota River drainage.

The following table gives the daily stage and rate of flow of the larger floods from 1867 to 1904. The discharge is taken from a station rating table prepared from observations made by engineers of the United States Army in April and May, 1897. The daily rate of flow during the flood of 1881 is in doubt. It was less than 120,000 second-feet and greater than 95,000 second-feet.

Flood flow of Mississippi River at St. Paul, Minn., 1867–1904.[a]

[Drainage area, 36,085 square miles. Highest water, 19.7 feet, April 29, 1881; lowest, 0.9 foot, March 19, 1896. Danger line, 14 feet.]

Year.	Date.	Gage height.[c]	Discharge.	Year.	Date.	Gage height.[c]	Discharge.
		Feet.	*Sec.-feet.*			*Feet.*	*Sec.-feet.*
1867	April 21	16.8	74,880	1882	April 13	13.3	
	April 22	17.4	80,040	1883	April 25	12.2	
	April 23	17.1	77,460	1884	May 5	10.2	
	April 24	16.8	74,880	1885	June 18	7.4	
	April 25	16.4	71,500	1886	March 29	8.2	
	April 26	15.7	65,840	1887	April 17	9.6	
	June 14	16.2	69,900	1888	April 14	14.4	
	July 1	17.2	78,320	1889	May 21	4.5	
	July 23	18.6	91,560	1890	April 13	5.5	
1868	April 4	9.3		1891	April 17	6.4	
1869	April 7	15.6	65,020	1892	May 26	12.6	
	September 24–27	16.1	69,100	1893	May 5	14.7	
[b]1872	May 19–22	7.7		1894	May 21	11.8	
1873	April 29	16.0	68,300	1895	June 16	4.6	
	June 1	15.7	65,840	1896	April 18	10.7	
	June 13	15.5	64,200	1897	April 1	15.3	62,600
1874	July 1–2	11.6			April 2	16.4	71,500
1875	April 14	16.0	68,300		April 3	17.1	77,460
	April 15	17.0	76,600		April 4	17.4	80,040
	April 16	18.0	85,500		April 5	17.9	84,580
	April 17	17.8	83,640		April 6	18.0	85,500
	April 18	17.5	80,900		April 7	17.8	83,640
	April 19	17.0	76,600		April 8	17.7	82,700
	April 20	16.4	71,500		April 9	17.8	83,640
1876	May 22–23	10.4			April 10	17.7	82,750
1877	May 25	7.7			April 11	17.5	80,900
1878	April 27	6.7			April 12	17.1	77,460
1879	July 11	10.8			April 13	16.6	73,160
1880	June 17–18	15.2	61,800		April 14	16.2	69,900
1881	April 26	15.3	62,600		April 15	15.7	65,840
	April 27	17.9	84,580		April 16	15.2	61,800
	April 28	19.0	95,000	1898	June 8	10.7	
	April 29	[d]19.5	to	1899	June 22	11.0	
	April 30	19.3	120,000	1900	September 25–28	6.0	
	May 1	18.7	92,620	1901	April 12	7.5	
	May 2	17.8	83,640	1902	June 9	6.8	
	May 3	16.3	70,750	1903	October 14	13.5	
	May 4	15.8	66,660	1904	April 11	9.9	

[a] Tabulated results of discharge observations Mississippi River and tributaries, 1897–98, p. 184.
[b] Records for 1870–71 missing.
[c] U. S. Weather Bureau gage records.
[d] Maximum, 19.7 feet.

The largest flood at St. Paul in these thirty-nine years was in April, 1881, when the rate of flow was from 2.63 to 3.33 second-feet per square mile. Second in size was the flood of July, 1867, which had a rate on the 23d of about 92,000 second-feet.

KANSAS RIVER.

The Kansas is formed by the junction of Republican and Smoky Hill rivers in central Kansas, flows eastward for a distance of 180 miles, and empties into Missouri River. The two streams that form the Kansas rise in the foothills of the Rocky Mountains, in eastern Colorado. The basin including these streams has a length of 490 miles, a width of 140 to 190 miles, and an area of 61,440 square miles. It is rolling prairie country, the eastern third being under cultivation, the remainder covered with tough buffalo grass sod. There is little timber and no surface storage. The surface falls gradually from an elevation of about 5,500 feet to 750 feet at the mouth of the stream. The mean annual precipitation varies from about 12 inches in the western part to 35 or 40 inches in the eastern part. The river bottom ranges in width from 1 to 4 miles and is almost entirely submerged during the largest floods, the natural channel being entirely inadequate to pass the flood flow, the average slope of stream bed being only 1.8 feet per mile.

The following table gives the daily rate of flow of Kansas River at Lawrence or Lecompton, Kans., during the larger floods from 1881 to 1905:

Flood flow of Kansas River at Lawrence and Lecompton, Kans., 1881–1905.[a]

[Drainage area at Lawrence, 59.841 square miles; drainage area at Lecompton, 58,550 square miles.]

Year.	Date.	Discharge.	Year.	Date.	Discharge.
		Sec.-feet.			*Sec.-feet.*
1881	March 7	18,700	1895	August 19	17,390
1882	April 10	19,370	1896	July 20	53,300
1883	June 25	19,370	1897	April 26	67,700
1886	May 10	19,370	1898	June 10	28,990
1889	May 13	24,340	1899	July 8	[b] 30,250
	July 22	24,340	1900	March 10	[b] 24,900
1891	June 1	35,600	1901	April 14	[b] 25,000
1892	May 16	67,700	1902	July 15	[b] 81,400
1893	June 5	19,370	1903	May 31	[b] [c] 221,000
	June 25	26,620	1904	July 7	[b] 130,000
1895	June 10	17,390	1905	September 18	[b] 56,000

[a] This station is described in Water-Sup. and Irr. Paper No. 99, p. 208.
[b] At Lecompton, Kans.
[c] From May 28 to June 7 the discharge was above 100,000 second-feet.

The largest flood during this period occurred in May and June, 1903. It is fully described in Water-Supply Paper No. 96. The maximum daily rate of flow was 221,000 second-feet, or 3.78 second-feet per square mile. Although this rate is very small as compared with that of eastern streams of the same drainage, it was an exceedingly large flood for this stream and caused the loss of $22,000,000 worth of property in Kansas and at Kansas City, Mo.

During this flood the greatest daily rate of flow of Blue River, one of the tributaries of the Kansas, was 7.2 second-feet per square mile.

The spring floods in this basin, due to melting snow, are small compared with those that occur in May, June, and July.

In 1844 there was a flood in this basin that is said to have equaled or exceeded that of 1903, but there is little data concerning this flood.

RIO GRANDE.

The Rio Grande rises in the Rocky Mountains in the southern part of Colorado, flows in a southerly direction through New Mexico, in a southeasterly direction through Texas, and empties into the Gulf of Mexico. The basin above San Marcial is long and comparatively narrow and its area above the gaging station at that place is 28,067 square miles. The slopes are steep, bare, and impervious, with no surface storage. The precipitation is small and generally torrential, except that which falls as snow at the headwaters of the streams.

The following table gives the daily rate of flow of the Rio Grande at San Marcial, N. Mex., during the largest floods from 1895 to 1905:

Flood flow of the Rio Grande at San Marcial, N. Mex. 1895 to 1905.[a]

[Drainage area, 28,067 square miles.]

Year.	Date.	Discharge.	Year.	Date.	Discharge.
		Sec.-feet.			*Sec.-feet.*
1895	April 15	7,800	1904	October 1	8,550
1896	April 29	4,800		October 2	18,400
	May 15	4,800		October 3	19,700
1897	May 21	21,750		October 4	5,000
	June 3	10,750		Ocober 9	12,000
1898	April 30	11,300		October 10	24,000
	July 17	16,775		October 11	33,000
1899	July 20	4,655		October 12	24,800
1900	May 22	6,250		October 13	21,750
	September 9	8,500		October 14	15,900
1901	May 25	5,600	1905	May 23	28,600
1902	August 26	10,500		May 24	29,070
1903	June 18	18,880		May 25	23,540
1904	September 29	3,280		May 26	28,000
	September 30	7,550			

[a] A description of this gaging station is given in Water-Sup. and Irr. Paper No. 99, p. 382.

NOTE.—The discharge was zero during the months of July, August, and part of September, 1900.

The greatest rate of flow during this period was in October, 1904. The mean rate for October 11 was 33,000 second-feet, or 1.17 second-feet per square mile. This flood is described in Water-Supply Paper No. 147, pages 143 to 150.

Second in size to this was the flood of May, 1905, described on pages 34 to 38 of this paper. The maximum rate of flow was 1.04 second-feet per square mile.

WESTERN STREAMS.

The maximum rate of discharge of some of the important streams in the arid region is given in the following table:

Maximum rate of flow of certain western streams, by years, 1886–1905.

[Drainage areas above gaging stations, in square miles: Colorado, 37,000; Loup, 13,540; Platte, 56,870; Arkansas, 4,600.]

Year.	Colorado River at Austin, Tex.		Loup River at Columbus, Nebr.		Platte River at Columbus, Nebr.		Arkansas River at Pueblo, Colo.	
	Date.	Discharge.	Date.	Discharge.	Date.	Discharge.	Month.	Discharge.
		Sec.-feet.		Sec.-feet.		Sec.-feet.		Sec.-feet.
1886							May	7,660
1887							July	6,510
1888							June	[b] 2,760
1889							August	[b] 2,620
1890							May	[b] 3,270
1891							June	[b] 4,230
1892							June	[b] 4,750
1893							June	[b] 4,750
1894							June	
1895			June 3	9,100	June 1	27,200	July	5,000
1896	October	14,100	June 6	[a] 70,000	June 10	14,900	August	3,440
1897	January 2	11,000	July	27,000	June	31,000	June	3,750
1898	June 16	29,000	June	6,670	June	24,600	July	5,390
1899	June 8	103,400	July	6,980	May	25,770	June	4,890
1900	April 7	123,000	June	14,300	May	35,400	June	6,980
1901	July 13	40,900	June	5,900	April	28,400	May	11,060
1902	July 28	31,250	July	10,900	May	13,800	August	8,320
1903	February 27	32,500	August	20,000	May	21,600	June	6,100
1904	June 8	46,140	June	20,000	June	18,190	June	3,310
1905	April	51,190	July	25,800	June	51,100	June	6,460

[a] Mean rate from 7 p. m. June 6 to 2 a. m. June 7.
[b] At Canyon, Colo.

Maximum rate of flow of certain western streams, by years, 1886–1905—**continued.**

[Drainage areas above gaging stations, in square miles: Bear, 6,000; Humboldt, 10,780; Boise, 2,450; Weiser, 894.]

Year.	Bear River at Collinston, Utah.		Humboldt River at Golconda, Nev.		Boise River at Boise, Idaho.		Weiser River at Weiser. Idaho.	
	Month.	Discharge.	Month.	Discharge.	Month.	Discharge.	Month.	Discharge.
		Sec.-feet.		*Sec.-feet.*		*Sec.-feet.*		*Sec.-feet.*
1890	May	8,220						
1891	May	5,000						
1892	May	6,260						
1893	May	6,470						
1894	May	7,900						
1895	May	5,000			May	7,100	March	6,130
1896	May	5,650	June	1,614	June	40,130	May	17,940
1897	May	10,590	May	3,100	April	28,570	April	17,180
1898	June	5,320	March	485	May	8,250	April	3,880
1899	June	6,640	May	2,230	May	19,050	March	6,580
1900	May	4,650	June	464	May	11,960	March	8,120
1901	May	4,950	March	3,080	May	12,670	February	7,140
1902	June	3,340	June	523	May	8,190	February	7,340
1903	May	3,350	June	740	June	16,750	March	10,410
1904	May	6,700	April	1,060	April	19,680	March	11,620
1905	May	2,760	May	356	June	6,260		

[Drainage areas above gaging stations, in square miles: Tuolumne, 15 000, Kern, 2.345; Kings 1,742.]

Year.	Tuolumne River at Lagrange Cal.		Kern River at Rio Bravo ranch, Cal.		Kings River at Sanger, Cal.	
	Month.	Discharge.	Month.	Discharge.	Month	Discharge.
		Sec.-feet.		*Sec.-feet.*		*Sec.-feet.*
1889						
1890						
1891						
1892						
1893						
1894			May	2,210		
1895			May	5,380		
1896	March	11,800	June	3,610	May	22,100
1897	May	14,700	May	5,340	May	22,730
1898	April	7,800	April	1,340	April	7,820
1899	March	21,800	March	4,930	March	20,200
1900	November	14,440	May	1,970	November	15,700
1901	February	19,240	May	4,420	January	43,930
1902	April	12,690	April	3,760	April	26,380
1903	April	20,340	May	3,374	May	17,290
1904	May	17,850	June	3,170	May	15,700
1905	March	13,070	June	3,039	June	9,795

FLOOD-FLOW CHARACTERISTICS.

The flood-flow data on pages 56 to 85 are summarized in the following table, which gives the drainage area in square miles of each river basin above the place of measurement; the length of record, or number of years that flood observations have been made; the largest daily rate of flow during the period of observation; the largest range of stage during that period, and the number of times that floods of a given magnitude compared with the largest flood have occurred in the period. This comparison of magnitude is by rate of flow, not by stage, except in a few cases. The rate of flow per foot increase of stage is much greater for the higher stages than the lower ones, so that the frequency of the stage of from, say, 0.8 to 0.9 of the maximum stage is much greater than the frequency of the rate of flow of from 0.8 to 0.9 of the maximum rate of flow.

An examination of this table will show that the streams in certain sections have definite flood-flow characteristics. Streams Nos. 1 to 6 form a northern group. The larger floods on these streams all occur in the spring. They are due to the rapid melting of snow and are intensified at times by the formation of ice gorges. The depth of snow on the ground in the early spring and the rate at which it melts are the controlling flood factors on these streams. Floods due to rain alone are of about half the magnitude of the spring floods and of much shorter duration. The maximum rate of run-off of these streams is small (15 to 25 second-feet per square mile) compared with streams elsewhere of the same size of basin and depth of annual precipitation. Floods of the first or second magnitude (from 0.8 to 1 of the magnitude of the greatest recorded flood) may be expected to occur, on an average, once in twelve to fifteen years.

Streams Nos. 7 to 11 form a second group. The rate of flood flow is larger than that of the streams in group 1. Some of the large floods in the spring are due to melting snow and some are due entirely to rain. The summer floods are not so long in duration as the spring floods. Large floods in streams of this group are not so frequent as in those of group 1. They occur about once in twenty to forty years.

The length of record of the four southeastern streams (Nos. 12-15) is too short, except that of the Savannah, to include the largest flood. The range of stage is large. The frequency of occurrence and duration of floods are also large, because of sluggish flow. The largest flood occurred in the fall, and had a rate of flow somewhat less than the largest rate of flow in group 2.

The largest floods in the upper Ohio basin occur in the spring. Two exceptions are the flood of July, 1888, on the Monongahela, and that of August, 1888, on the Youghiogheny. They resemble somewhat those on streams of groups 1 and 2, but are more like the latter than the former.

The Illinois and upper Ohio rivers have a remarkably small rate of flood flow—less than 3½ second-feet per square mile. The large floods occur in the spring. The largest flood on Grand River, Michigan,[a] in probably a century had a maximum daily rate of about 8 second-feet per square mile of drainage area.

Streams 23-28 are in the arid and semiarid regions, and their rate of flood flow is very small. Very large floods occur rarely on those streams, and are due to heavy rain. Ordinary floods generally occur in the spring, and are due to melting snow. An exception to this rule is shown by Kansas River. The two great floods on Kansas River were about sixty years apart.

Other less important facts can be seen from a study of the data.

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[a] Water-Sup. and Irr. Paper No. 147, p. 40.

Data on flood flow of streams in the United States.

	Stream.	Place.	Drainage area, in square miles.	Length of record, in years.	Period of record.	Maximum daily rate, in second-feet, per square mile.	Range of stage, in feet.	Number of occurrences of magnitude of greatest rate of flow.			
								0.6 to 0.7.	0.7 to 0.8.	0.8 to 0.9.	0.9 to 10.
1	Kennebec	Waterville, Me	4,380	12	1893-1904	25.4	....	3	2	0	1
2	Androscoggin	Rumford Falls, Me	2,320	12	1893-1904	23.8	....	1	1	0	1
3	Merrimac	Lawrence, Mass	4,553	59	1846-1904	18.0	....	....	....	1	3
4	Connecticut	Hartford, Conn	10,234	105	1801-1905	20.0	....	....	....	7	2
5	Hudson	Mechanicsville, N. Y	4,500	35	1869-1903	15.6	....	....	....	1	1
6	Genesee	Rochester, N. Y	2,428	119	1785-1903	19 to 22	....	....	....	1	1
7	Passaic	Dundee, N. J	8,227	26	1878-1903	42.5	....	....	1	0	1
8	Raritan	Boundbrook, N. J	806	96	1810-1905	64.5	....	....	2?	1?	1
9	Delaware	Lambertville, Pa	6,855	120	1786-1905	37.1	....	....	0	2	1
10	Potomac	Point of Rocks, Md	9,650	17	1889-1905	48.9	....	0	0	0	1
11	Susquehanna	Harrisburg, Pa	24,030	17	1889-1905	28 to 30.6	....	....	1	1	1
12	Cape Fear	Fayetteville, N. C	3,860	15	1889-1903	18 to 23	57.3	[a]13	[a]17	[a]7	[a]2
13	Savannah	Augusta, Ga	7,500	66	1840-1905	40.0	36.8	[a]39	[a]31	[a]10	[a]2
14	Alabama	Selma, Ala	15,400	14	1891-1904	9.5	58.9	[a]6	[a]10	[a]6	[a]3
15	Black Warrior	Tuscaloosa, Ala	4,900	17	1889-1905	32.0	64.8	[a]10	[a]11	[a]12	[a]8
16	Monongahela	Lock No. 4, Pa	5,430	20	1886-1905	38.1	38.8	3	1	0	1
17	Youghiogheny	Confluence, Pa	782	32	[b]1874-1905	53.8 to 59.0	17.8	6	1	0	1
18	Allegheny	Freeport, Pa	9,220	31	[c]1874-1904	[d]26.7	37.5	[a]65	[a]17	[a]7	[a]4
19	Ohio	Wheeling, W. Va	23,800	22	1884-1905	20.8	53.4	3	5	1	1
20	Tennessee	Chattanooga, Tenn	21,382	38	1867-1904	34.4	58.0	....	0	0	1
21	Illinois	Peoria, Ill	15,700	16	1890-1905	3.3	19.3	....	2	2	3
22	Mississippi	St. Paul, Minn	36,085	38	1867-1904	3.3	19.0	....	....	....	3
23	Kansas	Lawrence, Kans	59,841	25	1881-1905	3.8	27.5	0	0	0	1
24	Rio Grande	San Marcial, N. Mex	28,067	11	1895-1905	1.17	....	1	0	1	1
25	Colorado	Austin, Tex	37,000	9	1896-1904	3.33	....	0	1	0	1
26	Loup	Columbus, Nebr	13,540	10	1895-1904	5.17	....	0	0	0	1
27	Arkansas	Pueblo, Colo	4,600	10	1895-1904	2.40	....	1	1	0	1
28	Bear	Collinston, Utah	6,000	15	1890-1904	1.76	....	3	2	0	1

[a] Number of occurrences of magnitude of greatest stage.
[b] Two years' records not complete.
[c] Three months of 1888 record missing.
[d] Maximum rate at Kittanning during flood of March, 1905.

INDEX TO FLOOD LITERATURE.

The following index to flood literature in the United States has been compiled from the indexes of the principal publications that treat of the subject. The floods have been indexed by streams and by the principal places affected by the flood. Throughout the index an attempt has been made to distinguish between the descriptions of flood and the flood discharges. The index is not exhaustive, but comprises, it is believed, all important articles:

Adams, N. Y., discharge of Sandy Creek at, 1897 and 1898.......Hydrology State of New York, 1905, p. 461

Ager's mill, N. Y., discharge of Moose River at, April, 1869.......Hydrology State of New York, 1905, p. 466

Albany, N. Y., flood damages at........................Eng. News, vol. 43, 1900, p. 132
  freshets and ice gorges at...............Hydrology State of New York, 1905, p. 469

Allegan, Mich., discharge of Kalamazoo River at, March, 1903....Water-Supply Paper No. 83, U. S. Geol. Survey, 1903, pp. 268, 269

Allegheny River, N. Y., floods on, at Red House, 1832 and 1865.....Water-Supply Paper No. 36, U. S. Geol. Survey, 1900, p. 158

Arizona dam, discharge of Salt River at, February, 1890, and February, 1901...12th Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 312–313

Arkansas City, Ark., flood at, June, 1904.......Water-Supply Paper No. 147, U. S. Geol. Survey, 1905, p. 110

Arkansas River, discharge of, at La Junta, Colo., May, 1894...Bulletin No. 131, U. S. Geol. Survey, pp. 37, 38
  discharge of, at Syracuse, Kans., October, 1904.........Water-Supply Paper No. 147, U. S. Geol. Survey, 1905, p. 169
  flood on, June, 1904....Water-Supply Paper No. 147, U. S. Geol. Survey, 1905, p. 109
    September, 1904....Water-Supply Paper No. 147, U. S. Geol. Survey, 1905, p. 165
  great floods on..Rept. on Physics and Hydraulics of Mississippi River, by.......... Humphreys and Abbott, p. 46

Augusta, Ga., discharge of Savannah River at, 1884 and 1891...........14th Ann. Rept. U. S. Geol. Survey, pt. 2, p. 149
  levees proposed for protection of.....Rept. Chief Eng. U. S. A., 1900, pp. 1496–1498

Austin, Tex., discharge of Colorado River at, 1889..........Water-Supply Paper No. 40, U. S. Geol. Survey, 1900, p. 31

Baldwinsville, N. Y., discharge of Seneca River at, July, 1902........Hydrology State of New York, 1905, p. 458

Beaver River, N. Y., discharge of, at Beaver Falls, 1869.............Hydrology State of New York, 1905, p. 466

Belle Fourche River, S. Dak., discharge and flood on, at Belle Fourche.....Water-Supply Paper No. 147, U. S. Geol. Survey, 1905, pp. 55, 57

Big Sandy Creek, Ariz., discharge of, August, 1904.........Water-Supply Paper No. 147, U. S. Geol. Survey, 1905, pp. 115–118

Binghamton, N. Y., discharge of Susquehanna River at, 1865 and 1902........Hydrology State of New York, 1905, p. 486; Water-Supply Paper No. 82, U. S. Geol. Survey, 1903, pp. 147–150
  discharge of Chenango River at, 1902....Hydrology State of New York, 1905, p. 487

Black River, N. Y., discharge of, near Carthage, April, 1869..........Hydrology State of New York, 1905, p. 465
  discharge of, near Carthage, Forestville, Lyons Falls, Ontario Paper Mills, and Watertown, April, 1869.........Water-Supply Paper No. 65, U. S. Geol. Survey, 1902, p. 105

Blue River, Kans., flood on, at Manhattan, May and June, 1903.....Water-Supply Paper No. 96, U. S. Geol. Survey, 1904, p. 36
  flood on, at Manhattan, June, 1904........Water-Supply Paper No. 147, U. S. Geol. Survey, 1905, p. 74

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CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 162.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States, folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

Most of the above publications may be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are delivered to Senators and Representatives in Congress, for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they may be had at slightly above cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they may be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the seventeenth in Series M, the complete list of which follows. (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper.

SERIES M—GENERAL HYDROGRAPHIC INVESTIGATIONS.

WS 56. Methods of stream measurement. 1901. 51 pp., 12 pls.
WS 64. Accuracy of stream measurements, by E. C. Murphy. 1902. 99 pp., 4 pls.
WS 76. Observations on the flow of rivers in the vicinity of New York City, by H. A. Pressey. 1902. 108 pp., 13 pls.
WS 80. The relation of rainfall to run-off, by G. W. Rafter. 1903. 104 pp.
WS 81. California hydrography, by J. B. Lippincott. 1903. 488 pp., 1 pl.
WS 88. The Passaic flood of 1902, by G. B. Hollister and M. O. Leighton. 1903. 56 pp., 15 pls.
WS 91. Natural features and economic development of the Sandusky, Maumee, Muskingum, and Miami drainage areas in Ohio, by B. H. Flynn and M. S. Flynn. 1904. 130 pp.
WS 92. The Passaic flood of 1903, by M. O. Leighton. 1904. 48 pp., 7 pls.
WS 94. Hydrographic manual of the United States Geological Survey, prepared by E. C. Murphy, J. C. Hoyt, and G. B. Hollister. 1904. 76 pp., 3 pls.
WS 95. Accuracy of stream measurements (second edition), by E. C. Murphy. 1904. 81 pp., 13 pls.
WS 96. Destructive floods in the United States in 1903, by E. C. Murphy. 1904. 81 pp., 13 pls.
WS 106. Water resources of the Philadelphia district, by Florence Bascom. 1904. 75 pp., 4 pls.
WS 109. Hydrography of Susquehanna River drainage basin, by J. C. Hoyt and R. H. Anderson. 1905. 215 pp., 29 pls.
WS 116. Water resources near Santa Barbara, California, by J. B. Lippincott. 1904. 99 pp., 8 pls.
WS 147. Destructive floods in the United States in 1904, by E. C. Murphy and others. 1905. 206 pp., 18 pls.
WS 150. Weir experiments, coefficients, and formulas, by R. E. Horton. 1906. 189 pp., 38 pls.
WS 162. Destructive floods in the United States in 1905, by E. C. Murphy and others. 1906. 105 pp., 4 pls.

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CHARLES D. WALCOTT, DIRECTOR

BIBLIOGRAPHIC REVIEW AND INDEX

OF

UNDERGROUND-WATER LITERATURE

PUBLISHED IN THE UNITED STATES

IN 1905

BY

MYRON L. FULLER, FREDERICK G. CLAPP,
AND BERTRAND L. JOHNSON

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BIBLIOGRAPHIC REVIEW AND INDEX OF UNDERGROUND-WATER LITERATURE PUBLISHED IN THE UNITED STATES IN 1905.

By Myron L. Fuller, Frederick G. Clapp, and Bertrand L. Johnson.

INTRODUCTION.

To meet the urgent need which was felt for more definite information as to underground-water publications in the United States, plans for bibliographies of such literature were made, in 1903, on the organization of the division of hydrology. A bibliography of the publications of the United States Geological Survey, which has been the leading contributor to such literature, was prepared in accordance with these plans and published in 1905.

The scope of the present bibliography has been extended to cover all publications in the United States which seemed likely to contain important references to underground waters, technical and trade journals as well as the more strictly scientific contributions being reviewed. The reports of the Canadian Geological Survey are also included. The list of publications examined will be found on page 6. The attempt has been made to render this compilation as complete as possible, to which end not only have the papers dealing mainly with underground waters been reviewed but many general papers have been scanned for incidental references. There are 721 titles in the bibliography.

As in the case of the previous bibliography, two distinct classes of readers were kept in mind in preparing the index, the first including those who are interested in the underground-water resources of special regions and the second those who are interested in some particular type of ground water or in one or more of the many problems of ground-water occurrence. For the benefit of the first class, comprehensive entries are given under States and other political or natural divisions, while the numerous subject entries will appeal to readers of the second class. The aim has been to assemble the subject entries into comprehensive groups, each including all references to papers containing material bearing on the subject of the group. The State entries will be found the most complete, as they include many which it is impossible to classify satisfactorily.

The subject entries, as in the preceding bibliography, are grouped into series of what may be termed principal subject entries, but a large number of entries, including those which it was impracticable to classify, together with numerous cross references, are included with the view of increasing the usefulness of the index.

LIST OF PUBLICATIONS EXAMINED.

The publications examined in preparing this bibliography and index include such of the following as were published in 1905 and received at the Department libraries in Washington prior to March 1, 1906.

Alabama Geological Survey: Bulletin; Index to Mineral Resources
American Academy of Arts and Sciences: Proceedings.
American Academy of Natural Sciences: Proceedings.
American Chemical Journal.
American Chemical Society: Journal.
American Geographical Society: Bulletin.
American Institute of Mining Engineers: Bimonthly Bulletin.
American Journal of Science.
American Philosophical Socitey: Proceedings.
American Society of Civil Engineers: Proceedings and Transactions.
American Waterworks Association: Proceedings.
Appalachia.
Association of Civil Engineers of Cornell University: Transactions.
Association of Engineering Societies: Journal.
Boston Society of Natural History: Proceedings.
California Journal of Technology.
Canada Geological Survey: Summary Report for 1904.
Carnegie Institution of Washington: Yearbook.
Cassier's Magazine.
Census of the Philippine Islands for 1903.
Chemical Engineer.
Colorado Scientific Society: Proceedings.
Compressed Air.
Connecticut State Board of Health: Twenty-seventh Annual Report.
Daily Consular Reports.
Elisha Mitchell Scientific Society: Journal.
Engineering and Mining Journal.
Engineering Magazine.
Engineering News.
Engineering Record.
Engineering Society of Western Pennsylvania: Proceedings.
Engineers' Club of Philadelphia: Proceedings.
Experiment Station Record.
Forestry and Irrigation.
Franklin Institute: Journal.
Georgia Geological Survey: Bulletin.
Harvard College, Museum of Comparative Zoology: Bulletin.
Illinois Society of Engineers and Surveyors: Twentieth Annual Report.
Indiana, Department of Geology and Natural Resources: Annual Report.
Iowa Geological Survey: Annual Report for 1904.
Irrigation.
Irrigation Age.
Irrigation Aid.
Journal of Geography.
Journal of Physical Chemistry.
Kansas State Board of Health: Second Biennial Report.
Louisiana Geological Survey: Bulletins.
Michigan Geological Survey: Reports.
Mines and Minerals.
Mining and Scientific Press.
Mining Magazine.
Mining Reporter.
Missouri Geological Survey: Biennial Report.
Monthly Weather Review.
Municipal Engineering.
New England Waterworks Association: Journal.
New Jersey Geological Survey: Annual Report.
New Jersey State Board of Health: Report for 1904.
New York Academy of Sciences: Annals.
New York State Museum: Bulletins.

North Carolina Geological Survey: Bulletins, vol. 1.
North Carolina State Board of Health: Tenth Report.
Philippine Commission: Report for 1904.
Popular Science Monthly.
Proceedings of the Twelfth National Irrigation Congress, El Paso, Tex., 1904.
Progressive Age.
Science.
Scientific American.
Scientific American Supplement.
School of Mines Quarterly.
Smithsonian Institution: Annual Report.
Technical World Magazine.
Technology Quarterly.
United States Department of Agriculture: Annual Reports; Farmers' Bulletins; Secretary's Report; Twentieth Annual Report; Yearbook.
United States Department of Agriculture, Bureau of Chemistry: Bulletins; Circulars.
United States Department of Agriculture, Bureau of Soils: Bulletins; Field Operations for 1904.
United States Department of Agriculture, Office of Experiment Stations: Bulletins.
United States Geological Survey: Twenty-fifth and Twenty-sixth Annual Reports; Bulletins; Folios; Mineral Resources for 1904; Water-Supply and Irrigation Papers.
United States National Museum: Proceedings.
University of California: Bulletin of the Department of Geology.
Washington Academy of Science: Proceedings.
Water and Forest.
Western Society of Engineering: Journal.

BIBLIOGRAPHIC REVIEW.

A.

1 **Adams** (Frank). The distribution and use of water in the Modesto and Turlock irrigation districts, California.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, pp. 93–139, 3 pls., 1 fig.
Discusses rise of water table due to irrigation (pp. 126–129).

2 **Adams** (George I.). Summary of the water supply of the Ozark region in northern Arkansas.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 179–182, 1 fig.
Classifies the springs of the region on the basis of their relations to various limestone, sandstone, dolomite, and shale formations, and notes their extensive use for health resorts.

3 **Alexander** (A. B.). How tile drainage improves a soil.

Twentieth Ann. Rept. Ill. Soc. Eng. and Surv., pp. 66–68.
A discussion of the benefits obtained by underdrainage. Excess soil water may be due to rainfall or seepage from soils at higher levels. Discusses the relation of the level of the ground water table to plant life and the movements resulting in a saturated soil from alternate freezing and thawing.

4 **Allen** (Kenneth). The sanitary protection of water supplies.

Jour. Franklin Institute, vol. 160, pp. 297–323.
Mentions the epidemic caused by the pollution of the Broad street well in London in 1854; Frankland's experiments on the life of typhoid bacteria in deep-well waters; examination by Whipple of the depth of penetration of bacteria into the sands of Long Island; use of copper sulphate in the purification of a polluted spring water. States that artesian waters contain no bacteria.

5 **Anderson** (George E.). Well-boring machinery and pumps in China.

Daily Consular Repts. no. 2170, Dept. Com. and Labor, pp. 10–11.
Discusses need of wells, well-boring machinery, pumps, and underground-water supplies in Chinese cities.

6 **Arnold** (Ralph). Coal in Clallam County, Washington.

Bull. U. S. Geol. Survey no. 260, pp. 413–421.
Notes an abandoned 1,500-foot well (p. 415) and gives a well record (p. 418).

7 **Ashley** (George H.). Water resources of the Middlesboro-Harlan region of southeastern Kentucky.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 177–178.
Describes one flowing artesian well from the Lee conglomerate. Mentions abundance of good springs.

8 **Ashley** (George H.). Water resources of the Nicholas quadrangle, West Virginia.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 64–66.

Outlines the underground-water conditions, stating that shallow wells are largely used on the ridges, while springs are an important source of water on the slopes and in valleys. A few deep wells and a waterworks system are located at Richwood. The shallow wells are likely to go dry in summer, but the springs, although small, are more constant. The horizon of the Gauley coal is characterized by many springs. The conditions are considered favorable for artesian wells.

9 **Atkinson** (James P.). Shallow-well waters of Brooklyn.

Abstract: Science, new ser., vol. 21, p. 987.

Concludes that the wells are in serious danger of pollution by sewage.

10 **Ayrs** (O. L.), **Mooney** (Charles N.) and. Soil survey of the Greenville area, Tennessee-North Carolina.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 493–525, 1 map, 1 fig.

See Mooney (Charles N.) and Ayrs (O. L.).

B.

11 **Babb** (Cyrus C.) and **Hoyt** (John C.). Report of progress of stream measurements for the calendar year 1904: Part VII, Hudson Bay, Minnesota, Wapsipinicon, Iowa, Des Moines, and Missouri River drainages.

Water-Sup. and Irr. Paper no. 130, U. S. Geol. Survey, 204 pp.

Gives measurements of seepage (p. 102) and of Giant springs in Montana (p. 192).

12 **Bain** (H. Foster). Zinc and lead deposits of northwestern Illinois.

Bull. U. S. Geol. Survey no. 246, 56 pp., 5 pls., 3 figs.

Describes enlargement of joint cracks in limestone through solution by underground waters (pp. 31–32) and deposition of ores in the cavities (p. 33). Describes relation of ores to level and circulation of underground water (pp. 35–36, 46–50). Gives drill record (p. 42).

13 —— The fluorspar deposits of southern Illinois.

Bull. U. S. Geol. Survey no. 255, 70 pp.

Considers the relation of ores to underground waters (p. 42) and notes the presence of water channels in the ore bodies (p. 47). The conditions of ore deposition in relation to underground waters are also discussed (pp. 57, 62, 66).

14 —— Principal American fluorspar deposits.

Min. Magazine, vol. 12, pp. 115–119, 1 fig.

Kentucky-Illinois deposits believed to have been formed by heated waters more or less directly connected with igneous intrusions.

15 —— The progress of economic geology in 1905.

Min. Magazine, vol. 12, pp. 465–473, 2 figs.

A brief summary of recent works on the agency of meteoric and magmatic waters in ore genesis is given (pp. 468–469).

16 **Barber** (Emmet). Pumping water by compressed air.

Irrigation Age, vol. 21, pp. 9–10, 4 figs.

Describes the use of compressed air in pumping water from an artesian well 865 feet deep at Waukena, Cal. A natural flow of 600 gallons per minute was increased to 2,400 gallons per minute by the use of compressed air.

17 **Barbour** (F. A.). The sewage-disposal works at Saratoga, N. Y.

Jour. Assoc. Eng. Soc., vol. 34, pp. 33–59, 28 figs.

Gives depth of water table as 16 feet below the surface at the filter beds and states that most of the filtrate runs off through the ground without appreciably raising the water table (p. 50).

18 **Bayley** (W. S.). Maine.

Water-Sup. and Irr. Papers no. 114, U. S. Geol. Survey, pp. 41–56, 1 fig.

Mentions conditions necessary for wells (p. 42). Describes city supply of Castine derived from driven wells (pp. 43, 46–47). Describes distribution of dug, drilled, driven, and bored wells, and gives map of flowing and nearly flowing wells (pp. 47–49). Gives table of 27 communities obtaining public supply from springs (p. 46). Describes distribution of ordinary and commercial springs (pp. 48–50), and gives table of 47 commercial springs, with their yields, temperatures, and analyses (pp. 51–56).

19 **Beaumont Journal.** Some Texas canals and wells.

Irrigation Aid, vol. 1, no. 6, p. 9.

Gives a list of canals supplied by well water and used for irrigation.

20 **Bennett** (Frank) and **Ely** (Charles W.). Soil survey of Marshall County, Ind.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 689–706, 1 map, 1 fig.

Mentions occurrence of springs and flowing artesian wells in the drift (p. 693).

21 —— and **Griffin** (A. M.). Soil survey of the Orangeburg area, South Carolina.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 185–205, 1 map, 1 fig.

Mentions depth to water in various sections, and in artesian wells at Bowman and Branchville (p. 188).

22 **Bigelow** (Henry B.). The shoal-water deposits of the Bermuda Banks: Contributions from the Bermuda Biological Station for Research, No. 5.

Proc. Am. Acad. Arts and Sci., vol. 40, pp. 557–592, 4 maps.

The limestones of which the islands consist were consolidated from wind-blown sand by the action of percolating waters. Short descriptions of the caves, sinks, and subterranean channels in these limestones are given.

23 **Bigelow** (W. D.). Foods and food control, revised to July 1, 1905.

Bull. Bureau of Chem., U. S. Dept. Agr., no. 69 (revised), pts. 1 and 2, 1905, 200 pp.

States the laws of Connecticut (p. 96) and Indiana (p. 179) regarding pollution of spring and well water.

24 **Bingelmann** (M.). Ground water.

Jour. Agr. Prat., new ser., vol. 8, pp. 739–741, 5 figs.; pp. 771–773, 7 figs. Abstract: Exp. Sta. Record, vol. 17, no. 2, p. 118.

Discusses briefly the conditions which influence the percolation and level of ground water and the formation of springs.

25 **Blanchard** (C. J.). The to-morrow of Nevada.

Irrigation, vol. 3, no. 4, pp. 5–6, 3 figs.

Mentions the sinking of the mountain streams into the sands of the desert and notes the availability of the underflow of streams and artesian water for the irrigation of the arid lands.

26 **Blanchard** (C. J.). Reclamation work in southern California.

Sci. Am., vol. 92, pp. 499.

A general description of the underground water resources of the area is given. Notes the use of seepage water, artesian-well water, and water from tunnels in the mountains in irrigation. Describes artesian conditions in the valleys and plains. Notes decline of water level due to immense drain on the underground waters for irrigation and other purposes, and mentions the work of the United States Geological Survey in making observations on the fluctuations of ground-water levels in the area.

27 **Blatchley** (W. S.). The clays and clay industries of Indiana.

Twenty-ninth Ann. Rept. Indiana Dept. Geol. and Nat. Res., pp. 13–657, 32 pls., 10 figs.

Discusses origin of kaolin through agency of percolating water (pp. 56–57); gives records of many bore holes and wells, some flowing (pp. 102–501), and chemical analyses of spring and well water (pp. 185, 193, 349).

28 —— The petroleum industry in Indiana in 1904.

Twenty-ninth Ann. Rept. Indiana Dept. Geol. and Nat. Res., pp. 781–799.

Gives several brief records of oil wells (pp. 782–787).

29 **Boltwood** (Bertram B.). On the radio-active properties of the waters of the springs on the Hot Springs Reservation, Hot Springs, Ark.

Am. Jour. Sci., 4th ser., vol. 20, pp. 128–132.

Samples of water from 44 of the springs were examined for radio-active gases and solids. The tufa of some of the springs was also examined. Describes the results obtained, gives the location, total flow, temperatures, and total solids in the springs, and states that no connection can be established between these properties and the radio-active properties.

30 **Booth** (W. H.). Air-lift pumps.

Compressed Air, vol. 10, pp. 3403–3407, 3 figs. Also in Electrical Review (Eng.).

Mentions the existence of many artesian wells in the vicinity of London the water of which is used in the raising of water cress. The temperature of the water is given as 51°. Many of the wells do not flow now because of excessive use of the underground waters by waterworks.

31 **Booth** (William M.). Boiler waters and their treatment.

Chemical Engineer, vol. 1, pp. 279–287.

Notes the occurrence of sulphuric acid in the waters of coal mines (p. 282); states that the ground waters of central New York are high in chlorides (p. 285).

32 **Boutwell** (John Mason). Genesis of the ore deposits at Bingham, Utah.

Bimonthly Bull. Am. Inst. Min. Eng., pp. 1153–1192, 13 figs.

Notes a few good springs, but states that the main sources of supply are subterranean courses tapped by underground workings (p. 1155); the agency of mineralized underground waters in the formation of the deposits is discussed in detail.

33 —— Ore deposits of Bingham, Utah.

Eng. and Min. Jour., vol. 79, pp. 1176–1178, 3 figs.

Discusses the agency of underground waters in the genesis of these deposits.

34 —— Oil and asphalt prospects in the Salt Lake basin, Utah.

Bull. U. S. Geol. Survey no. 260, pp. 468–479.

Among subjects considered are mound springs emitting gas (p. 471), blows of gas and water from wells (p. 472), pitch springs (p. 474), salt water in wells (p. 477), thermal wells (p. 477), artesian waters (p. 478), and well records (pp. 471–472).

35 **Boutwell** (John Mason). Economic geology of the Bingham mining district, Utah.

Prof. Paper U. S. Geol. Survey no. 38, pp. 71–385, 34 pls., 10 figs.

Discusses physical and chemical characters of heated ore-bearing solutions (p. 176) and present mine waters (pp. 213–214), and summarizes the process of deposition (pp. 183, 210, 229). Discusses the relation of fissures to passage of mineral-laden solutions (pp. 199–201) and relation of water level to depth of superficial alteration (pp. 217–218, 225). Explains interference of ground water with placer working (pp. 377–378).

36 **Bowie** (Aug. J., jr.). Irrigation in southern Texas.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, pp. 347–507, 2 pls., 18 figs.

Describes briefly the water-bearing strata (pp. 354–355) and artesian districts (pp. 355–356) and a number of springs used for irrigation (pp. 356–357). Describes hydraulic-rig method of boring wells (pp. 357–358), strainers used in wells (pp. 358–362), and cost of well boring (pp. 362–364). Describes numerous flowing and nonflowing wells and springs used for irrigation, and methods and cost of pumping the nonflowing wells (pp. 378–474). Gives well records (pp. 381, 388, 394, 403, 459). Compares cost of artesian-well and pumped-well irrigation (pp. 488–490). Gives lists of flowing artesian wells (pp. 502–504) and pumped wells (pp. 505–506) in southern Texas.

37 **Bowman** (Isaiah). Disposal of oil-well wastes at Marion, Ind.

Water-Sup. and Irr. Paper no. 113, U. S. Geol. Survey, 1905, pp. 36–48.

Gives well records (pp. 38–39, 42). Describes the water-bearing conditions of the Niagara limestone (pp. 41–42), Hudson River limestone (p. 42) and Trenton limestone (pp. 42–43), and the contamination of the water-bearing beds by oil and brine from oil wells (pp. 43–48).

38 —— A classification of rivers based on water supply.

Jour. Geog., vol. 4, pp. 212–220.

Principally a translation by Mr. Bowman of a chapter in Woeikof's "Der Klimate der Erde," relating to the periodic rise and fall of streams. Contains a short discussion of the relation of ground water to the flow of streams.

39 **Bownocker** (J. A.). Salt deposits in northeastern Ohio.

Am. Geologist, vol. 35, pp. 370–376.

Mentions the occurrence of salt springs (p. 370) and gives a number of well records (pp. 371–376).

40 **Bowron** (William M.). The origin of Clinton red fossil ore in Lookout Mountain, Alabama.

Bimonthly Bull. Am. Inst. Min. Eng., no. 6, pp. 1245–1262, 3 figs.

Discusses the agency of underground waters in the formation of this ore.

41 **Branner** (John Casper). Stone reefs on the northeast coast of Brazil.

Bull. Geol. Soc. America, vol. 16, pp. 1–12.

Gives record of boring (p. 3) and ascribes cementation of the reefs to deposition of calcareous matter from percolating acid waters from the land at the point where they meet the salt waters of the ocean.

42 **Breneman** (A. A.). Mineral waters at the St. Louis Exposition.

Abstract: Science, new ser., vol. 21, pp. 819–820.

Mentions several features of the American and foreign exhibits, and compares them with the exhibits at Chicago in 1893.

43 **Brittain** (Joseph I.). Mineral springs of Baden-Baden (Germany).

Daily Consular Repts. no. 2193, Dept. Com. and Labor, p. 14.

Summarizes the number, depth, composition, and temperature of the springs and their economic value to Baden Baden as a health resort.

44 **Brooks** (Alfred Hulse). Placer mining in Alaska in 1904.
Bull. U. S. Geol. Survey no. 259, pp. 18–31.
Notes trouble in mines due to encountering water below frozen ground (pp. 27, 30).

45 **Brown** (R. Gilman). Some pumping data.
Eng. and Min. Jour., vol. 79, pp. 947–948.
Describes the unwatering of the Brunswick mine, Grass Valley, Cal., the flooding of which was caused by the cutting of a large flow of water on the 1,250-foot level.

46 **Brunton** (D. W.). Drainage of the Cripple Creek district [Colorado].
Eng. and Min. Jour., vol. 80, pp. 818–821, 5 figs.
Gives a definition of "ground water;" describes the permeability of the rocks, the amount of water removed to lower the water level 1 foot, the history of the previous tunnels, efficiency of tunnel drainage, depth at which tunnel should be driven, comparison of tunnel sites, etc.

47 **Brush** (Harlan W.). Simplon tunnel.
Daily Consular Repts. no. 2274, Dept. Com. and Labor, pp. 4–6.
Mentions hot springs of great volume encountered during work on the Simplon tunnel in Italy and Switzerland and consequent danger to operations (p. 5).

48 **Buckley** (Ernest Robertson). Biennial report of the State geologist transmitted by the board of managers of the Bureau of Geology and Mines to the Forty-third General Assembly.
Jefferson City, Mo., 50 pp., 1 map.
Summarizes the data obtained by the bureau relating to mineral springs (p. 48).

49 **Burchard** (Ernest F.). Iron ores in the Brookwood quadrangle, Alabama.
Bull. U. S. Geol. Survey no. 260, pp. 321–334.
Gives well record and describes spring (p. 327) and considers the possible action of water in ore formation (pp. 333–334).

49a **Burdick** (C. B.), **Maury** (Dabney H.), **Henderson** (C. R.) and. Report of the committee on waterworks.
Twentieth Ann. Rept. Illinois Soc. Eng. and Surv., pp. 132–139.
See Maury (Dabney H.), Burdick (C. B.), and Henderson (C. R.).

C.

50 **Caine** (Thomas A.) and **Lyman** (W. S.). Soil survey of the San Antonio area, Texas.
Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 447–473, 1 map, 1 fig.
Discusses irrigation and city water supply from artesian wells and springs, and the effect of the wells on the flow of the springs (pp. 467–468).

51 **Calkins** (Frank C.). Geology and water resources of a portion of east-central Washington.
Water-Sup. and Irr. Paper no. 118, U. S. Geol. Survey, 96 pp.
Discusses the topography and geology of the region in detail and describes the springs from alluvium, basalts, etc., where cut by canyons, and from fissures. One thermal spring is noted. The artesian conditions are considered by districts and the wells described. The deep waters are from the Ellensburg beds and the basalts and tuffs. The cost of drilling, the methods of testing and casing, artesian requisites, etc., are also discussed. Predictions as to supplies are given and the use of tunnels for the collection of surface supplies suggested.

52 **Cameron** (F. K.). The water of Utah Lake.

Jour. Am. Chem. Soc., vol. 27, pp. 113–116.

Describes the occurrence of numerous hot and cold springs in the bed of the lake which supply the greater part of the lake water. Gives several analyses of the lake water taken in the vicinity of some of the larger springs.

53 **Canfield** (R. B.). [Water problems of Santa Barbara, Cal.]

Water-Sup. and Irr. Paper no. 116, U. S. Geol. Survey, pp. 21–22 (reprint of portion of private report made in 1896).

Notes use of collecting tunnel and describes unsuccessful efforts to obtain large supplies from boring.

54 **Carr** (M. E.), **Hearn** (W. Edward) and. Soil survey of the Biloxi area, Mississippi.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 353–374, 1 map, 1 fig.

See Hearn (W. Edward) and Carr (M. E.).

55 **Catherinet** (Jules). Copper Mountain, British Columbia.

Eng. and Min. Jour., vol. 79, pp. 125–127, 6 figs.

Discusses the agency of underground waters in the formation of the copper deposits of this mountain.

56 **Chalon** (Paul F.). The genesis of metalliferous deposits and eruptive rocks.

Min. Magazine, vol. 12, pp. 507–510.

This article is an abstract of a memoir presented before the recent International Congress of Mining, Metallurgy, etc., at Liege. Discusses the depth to which waters can penetrate, the alteration of the rocks by this water, its agency in aqueo-igneous fusion, and the formation of ore deposits and eruptive rocks.

57 **Chandler** (A. E.), **Hinderlider** (M. C.), **Swendsen** (G. L.) and. Report of progress of stream measurements for the calendar year 1904. Part X, Colorado River and the Great Basin drainage.

Water-Sup. and Irr. Paper no. 133, U. S. Geol. Survey, 384 pp.

See Hinderlider (M. C.), Swendsen (G. L.), and Chandler (A. E.).

58 **Clapp** (Frederick Gardner). Water resources of the Curwensville, Patton, Ebensburg, and Barnesboro quadrangles, Pennsylvania.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 159–163.

Describes the iron, alum, and magnesia springs at Cresson, and gives analyses. Notes the abundance of good springs and describes several town supplies obtained from springs. Describes well waters used for public, private, and factory supplies. Notes one flowing artesian well and discusses the probability of obtaining further artesian supplies in the area.

59 **Cleland** (Herdman F.) The formation of natural bridges.

Am. Jour. Sci., 4th ser., vol. 20, pp. 119–124, 3 figs.

Suggests the following theory to account for the origin of the natural bridges at North Adams, Mass., Lexington, Va., Chattanooga, Tenn., in Utah, and in the Yellowstone National Park: "Before the formation of the bridge the stream which now flows under then flowed upon the surface of what is now the arch and probably plunged over a fall a short distance below the present site of the bridge. A portion of the water percolating through a joint plane or crack upstream discharged into the stream under the fall and gradually enlarged its passage by its solvent power. In the course of time this passage became sufficiently large to contain all of the water of the stream, and the bridge resulted."

60 **Coburn** (L. F.). Yreka waterworks system [California].

Municipal Engineering, vol. 29, pp. 437–438.

Notes the sinking of Yreka Creek in a bed of gravel about 2½ miles above Yreka and describes the building of a submerged concrete dam in the gravel at a narrow place in the creek. The water thus collected furnishes an abundant supply for the town of Yreka.

61 **Cole** (L. H.). The Centre Star mine, Rossland, B. C.

Min. and Sci. Press, vol. 90, p. 117, 1 fig.

Notes that the water in this mine is small in amount and noncorrosive.

62 **Coleman** (A. P.). Geology of the Sudbury district. [Ontario.]

Eng. and Min. Jour., vol. 79, pp. 189–190.

Criticizes Hiram W. Hixon's views of the aqueous origin of the Sudbury nickel ores.

63 **Colles** (George Wetmore). Mica and the mica industry; Pt. II, Geology.

Jour. Franklin Institute, vol. 160, pp. 275–294, 11 figs.

Contains a discussion of the agency of underground waters in the formation of the mica dikes. Notes also the alteration of the feldspathic contents of the dikes by percolating waters.

64 **Collins** (A. B.), **Wright** (A. E.) and. Irrigation near Garden, Kans., 1904.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, pp. 585–594.

See Wright (A. E.) and Collins (A. B.).

65 **Compressed Air.** [Water supply from wells at Los Angeles, Cal.]

Compressed Air, vol. 10, p. 3504.

A portion of the city supply is now furnished by 12 wells from 60 to 200 feet deep. The water is raised by compressed air.

66 —— The Simplon tunnel.

Compressed Air, vol. 10, pp. 3713–3717, 7 figs.

Contains a description of the springs encountered in constructing the Simplon tunnel in Switzerland and Italy, including location, temperature, and volume.

67 —— The Simplon tunnel.

Compressed Air, vol. 10, pp. 3811–3813, 1 fig.

Notes the encountering of hot springs in the Simplon tunnel in Switzerland and Italy and gives the volume and temperature of two of them.

68 **Cook** (Edward H.). La mina Santa Francisca, Mexico.

Min. Magazine, vol. 11, pp. 424–429, 5 figs.

Notes the impregnation of limestone by siliceous solutions (p. 425); gives an analysis of the ground water from the 450-foot level (p. 429); and discusses the agency of underground waters in the formation of the ore deposits (pp. 426–429).

69 **Cooper** (K. F.). An example of the legitimate use of water for domestic purposes.

Proc. Am. Soc. Civil Eng., vol. 31, pp. 475–478.

Describes the water-supply systems of the Lick Observatory on Mount Hamilton, California. The water for the domestic system is furnished by springs on the mountain side.

70 **Cooper** (W. F.). Water supply of the Lower Peninsula of Michigan.

Ann. Rept. Michigan Geol. Survey for 1903, pp. 47–109, 2 maps.

Describes the artesian-well areas, giving detailed descriptions, well records, and analyses, and states use for public and private supply; describes springs.

70a **Corstophine** (George S.), **Hatch** (Frederick H.) and. The origin of the Witwatersrand gold. [Transvaal.]

Eng. and Min. Jour., vol. 79, pp. 80–81.

See Hatch (Frederick H.) and Corstophine (George S.).

71 **Corthell** (E. L.). Discussion of paper entitled, "The reclamation of river deltas and salt marshes," by F. LeBaron.

Trans. Am. Soc. Civil Eng., vol. 54, pp. 83–87.

Gives records of several artesian wells in the vicinity of New Orleans, La.

72 **Courtis** (W. M.). Potassium salts.

Mineral Resources U. S. for 1904, U. S. Geol. Survey, 16 pp.

Contains a list of saline springs in the United States and partial analyses of the spring water showing potassium, sodium, and magnesium. States that "along the line of the fault on the rim of the Bighorn Basin, Wyoming, the waters are rich in potassium salts, running from 5 to 11 per cent of the total residue."

73 **Cox** (W. G.). Artesian-water supply.

Agr. Gaz. N. S. Wales, vol. 16, pp. 253–257, fig. 1. Abstract: Exp. Sta. Record, vol. 17, no. 2, p. 193.

Discusses the theoretical and practical use of artesian wells for water power in New South Wales and Queensland.

74 **Crane** (W. R.). The Quapaw zinc district [Indian Territory].

Eng. and Min. Jour., vol. 80, pp. 488–490, 3 figs.

Contains a short discussion of the agency of underground waters in the formation of the deposits.

75 —— Coal mining in Arkansas.

Eng. and Min. Jour., vol 80, pp. 774–777, 3 figs.

The mines are usually wet and the water is often acid, but good water for boilers is usually available (p. 776).

76 **Cravetti** (A. L.). Water and irrigation in the province of San Luis, Argentine Republic.

An. Min. Agr. Argentina, Sec. Agr. (Agron), vol. 1, no. 5, pp. 85–119, 6 figs. Abstract: Exp. Sta. Record, vol. 16, p. 1136.

Summarizes information regarding subterranean waters and their use for irrigation, etc.

77 **Crider** (A. F.). Cement resources of northeast Mississippi.

Bull. U. S. Geol. Survey no. 260, pp. 510–521.

Gives well sections (pp. 511, 516–517) and describes artesian flows (p. 517).

78 **Crosby** (William Otis). The limestone-granite contact deposits of Washington Camp, Arizona.

Bimonthly Bull. Am. Inst. Min. Eng., no. 6, pp. 1216–1238.

Contains a discussion of magmatic water in general and the improbability of its assistance in the development of the garnet contact zone at Washington Camp (pp. 1229–1232); suggests the concentration of metallic contents of the limestone by the circulation of the normal ground water stimulated by intense and long-continued igneous and metamorphic agencies (p. 1234); ascribes the occurrence of native arsenic at this place to thermal waters rising along a fault line (p. 1237).

79 —— Massachusetts and Rhode Island.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 68–75.

Describes briefly the occurrence of water and possibilities of artesian supply in Cambrian quartzite in the Berkshire Valley, in Triassic strata of the Connecticut Valley, in igneous and metamorphic rocks of the highlands, and in drift deposits (pp. 70–73). Enumerates the principal mineral springs in the two States (pp. 73–75). Gives list of publications (p. 75).

80 —— Water supply from the delta type of sand plain.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 161–178.

In connection with the location of dikes for the Metropolitan reservoir at Clinton, Mass., many hundred borings were made in the sand plains. The paper describes the evidence presented by these borings as to the water table, the artesian waters, the deposition of iron, the oxidation of the drift at considerable depths, and the phenomena of "lost water," or that taken up from the well by unsaturated beds.

81 **Culbertson** (Harvey). Irrigation investigations in western Texas.
Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, pp. 319–340, 4 figs.
Describes wells (some flowing artesian) (pp. 321, 323–325), and springs (pp. 323, 327–328) used for irrigation. Describes use of windmills for pumping water from wells (pp. 338–339).

82 **Cushing** (H. P.). Geology of the vicinity of Little Falls, Herkimer County [New York].
Bull. N. Y. State Mus. no. 77, 95 pp., 15 pls., 14 figs., 1 map.
Interprets geology on the basis of churn-drilled wells (pp. 53–56).

D.

83 **Dale** (T. Nelson). Water resources of the Fort Ticonderoga quadrangle, Vermont and New York.
Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 126–129.
Mentions the abundance of good springs, and refers to a well known as "the frozen well" on account of its extremely low temperature (p. 127).

84 **Darlington** (E. B.). Irrigation investigations, upper Snake River, Idaho.
Irrigation Age, vol. 20, pp. 204–207, 1 fig.
Notes large loss from irrigation canals by seepage and the reappearance of this water in springs and creeks. Abundance of water can be obtained from shallow wells near Rexburg (p. 206).

85 **Darton** (Nelson Horatio). Zuni salt deposits, New Mexico.
Bull. U. S. Geol. Survey no. 260, pp. 565–566.
Ascribes the supply of the salt lake to springs from the Red Beds.

86 —— Description of the Sundance quadrangle [Wyoming-South Dakota].
Geologic Atlas U. S., folio 127, U. S. Geol. Survey, 12 pp., 5 maps, 1 col. sect., 1 illus. sheet, 3 figs.
Discusses the water-bearing conditions of the Dakota and Lakota sandstones, Pahasapa limestone, Deadwood sandstone, Minnelusa formation, and Minnekahta limestone, and describes the relations of these beds to the occurrence of well and spring water (p. 12). Gives analysis of well water (p. 12). Shows the artesian-water conditions by means of a special colored map.

87 —— Preliminary report on the geology and underground water resources of the central Great Plains.
Prof. Paper U. S. Geol. Survey no. 32, 433 pp., 72 pls., 18 figs.
Describes the various water horizons and discusses in detail the artesian wells and artesian conditions in South Dakota, Nebraska, Kansas, eastern Colorado, and eastern Wyoming, giving numerous records. Describes salt springs and wells (pp. 389–392).

88 —— Delaware.
Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 111–113.
Enumerates various water horizons in Cretaceous and Tertiary strata, gives a partial list of deep wells, and states future prospects for wells. Notes the principal publications.

89 —— Preliminary list of deep borings in the United States, second edition, with additions.
Water-Sup. and Irr. Paper no. 149, U. S. Geol. Survey, 175 pp.
Contains lists of deep wells reported to the Survey or described in scientific publications. They are classified by States, counties, and towns, the depths, diameter, yield, height of water, temperature, and other miscellaneous data being presented in tables for each State and references being given to published records. Bibliographies of publications relating to deep borings are also included.

90 **Darton** (Nelson Horatio). The Zuni salt lake [Arizona].

Jour. Geol., vol. 13, pp. 185–193.

Quotes C. L. Herrick on suppossed derivation of salt from solution of salt in underlying strata (pp. 185–186). The salt is brought up by springs (pp. 187, 193). Suggests solution of salt beds by hot volcanic solutions as cause of sinking, producing the crater (pp. 190, 192).

91 —— and **Fuller** (Myron Leslie). Maryland.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 114–123, 2 pls.

Describes the distribution of springs and gives a list of those of commercial value (p. 115). Describes the distribution of wells in the Allegheny Plateau, the Appalachian Mountains, Piedmont Plateau, and Coastal Plain, and tabulates well statistics (pp. 116–118). Describes water horizons in the Coastal Plain formations (pp. 118–120), and discusses more fully the water horizons and well prospects of the Baltimore district (pp. 121–123). Lists the principal publications.

92 —— and **Fuller** (Myron Leslie). District of Columbia.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 124–126, 1 pl.

Describes occurrence of water in the crystalline rocks and in the Potomac formation. Notes several mineral springs, and several publications on the underground water of the District.

93 —— and **Fuller** (Myron Leslie). Virginia.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 127–135, 1 pl.

Describes various water horizons in the Cretaceous and Tertiary formations and gives sections (pp. 128–129). Gives table of deep wells and statistics (pp. 130–131). Describes underground water conditions in the Piedmont Plateau, Appalachian Mountain belt, and Cumberland Plateau (pp. 132–133). Lists the commercial springs (pp. 133–134) and publications on underground waters of the State (pp. 134–135).

94 —— and **O'Harra** (C. C.). Description of the Aladdin quadrangle [Wyoming-South Dakota-Montana].

Geologic Atlas U. S., folio 128, U. S. Geol. Survey, 8 pp., 4 maps, 1 col. sect., 1 fig.

Describes the water-bearing formations, including the Dakota-Lakota sandstone, Minnelusa formation, Pahasapa limestone, and Deadwood sandstone (p. 8), and notes the conditions relative to wells. The artesian-water conditions are shown by a special colored map.

95 **David** (T. W. E.), **Pittman** (E. F.) and. Irrigation geologically considered with special reference to the artesian area of New South Wales.

Jour. and Proc. Roy. Soc. N. S. Wales, Eng. sect., vol. 37, pp. clii–cliii, 2 pls. Abstract: Exp. Sta. Record, vol. 17, no. 2, p. 193.

See Pittman (E. F.) and David (T. W. E.).

96 **Davis** (F. S.). An undeveloped country.

Min. and Sci. Press, vol. 90, pp. 204–205, 4 figs.

Describes a spring in Lower California.

97 **Davis** (William Morris). "A journey across Turkestan."

Explorations in Turkestan, with an account of the basin of eastern Persia and Sistan.

Carnegie Institution of Washington, pp. 23–119, 67 figs.

Springs furnish a portion of the water supply of Baku (p. 29); a boring 2,000 feet deep at Askhabad failed to find water (p. 44). Notices a large spring in Firuza basin used for irrigation (p. 48). Notes seepage of water from terrace gravels into river (p. 103).

98 —— The Wasatch, Canyon, and House ranges, Utah.

Bull. Mus. Comp. Zool., Harvard Coll., Geological Series, vol. 8, pp. 15–56, 3 pls.

Describes a flowing well at Deseret (p. 35). Notes the obtaining of good water at Antelope and Indian Springs (p. 36). Mentions the ocurrence of springs in the House Range (p. 40).

99 **Davis** (William Morris). The geographical cycle in an arid climate.
Jour. Geol., vol. 13, pp. 381–407.
Mentions ground-water conditions in arid regions (p. 382) and considers underdrainage of deserts by sandstone in its possible relation to wind erosion (p. 392).

100 **Day** (David T.). Summary of the mineral production of the United States in 1904.
Mineral Resources U. S. for 1904, U. S. Geol. Survey, pp. 9–36.
Gives the production and value of mineral waters in the United States for 1904 (p. 21); comparison of the production and value for 1903 and 1904 (pp. 22–23); production and value of mineral waters each year from 1880 to 1904 (pp. 24–36).

101 **de Laval** (Carl George P.). Pumping on the Comstock. [Nevada.]
Eng. and Min. Jour., vol. 79, pp. 516–518, 7 figs.
Describes the encountering of water in the various mines on the lode and the quantity, temperature, etc., thereof.

102 —— Pumping the Comstock lode mines. [Nevada.]
Eng. Rec., vol. 51, pp. 360–361, 1 fig.
Describes the occurrences of hot water in these mines and the pumping machinery being used in the unwatering of the lode.

103 —— Pumping the Comstock lode mines. [Nevada.]
Mines and Minerals, vol. 26, pp. 78–79, 2 figs.
Describes the encountering of hot water in the mines on this lode.

104 —— Pumping the Comstock lode mines. [Nevada.]
Sci. Am. Supp., vol. 59, pp. 24484–24486, 9 figs.
Describes the encountering of hot water in the mines on this lode.

105 **Douglass** (Earl). Source of the placer gold in Alder Gulch, Montana.
Mines and Minerals, vol. 25, pp. 353–355, 3 figs.
Notes the possible agency of heated underground waters in the deposition of the gold occurring in the gravels.

105a **Drake** (J. A.), **Mangum** (A. W.) and. Soil survey of the Russell area, Kansas.
Field Operations of the Bureau of Soils, 1903, U. S. Dept. Agr., pp. 911–926, 1 fig., 1 map.
See Mangum (A. W.) and Drake (J. A.).

106 **Draper** (M. D.). The Goldfield district, Nevada.
Min. and Sci. Press, vol. 90, pp. 150–152, 10 figs.
Contains a discussion of the agency of solfataric waters in the formation of the deposits.

107 **Dravo** (F. R.). Concrete lining for mine shafts.
Proc. Eng. Soc. West. Pa., vol. 21, pp. 319–330, 2 figs.
Discusses the occurrence of springs, seepage water, etc., in mines, with especial reference to the use of concrete for shaft lining.

108 **Drummond** (Goyne). Reconnaissance of proposed ceded strip of Shoshone Indian Reservation, Wyoming.
Irrigation, vol. 2, no. 4, pp. 5–6.
Notes the sinking of Meadow Creek into a cave near the mouth of Little Wind River Canyon.

E.

109 **Eckel** (Edwin C.). The Clinton hematite.
Eng. and Min. Jour., vol. 79, pp. 897–898, 2 figs.
Quotes C. H. Smyth as to the agency of water in the formation of the iron ore.

110 **Eckel** (Edwin C.). Cement materials and industry of the United States.

Bull. U. S. Geol. Survey no. 243, 395 pp., 15 pls., 1 fig.

Discusses the percentage of water in freshly quarried limestone, clay, shale, and marl (pp. 44–45).

111 —— Limonite deposits of eastern New York and western New England.

Bull. U. S. Geol. Survey no. 260, pp. 335–342.

Notes part taken by water in ore deposition (p. 342).

112 **Elliott** (C. G.). Report on drainage investigations, 1904.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, pp. 643–743, 4 pls., 52 figs.

Discusses rise of ground water due to irrigation, and detection of rise by means of test wells (pp. 645–652). Notes porosity and cavernous nature of coral rock in Florida Everglades, as indicated by wells (p. 716).

113 **Ellis** (Edwin E.). Zinc and lead mines near Dodgeville, Wis.

Bull. U. S. Geol. Survey no. 260, pp. 311–315.

Notes the relation of ore to ground-water level and considers the conditions of deposition (pp. 314–315).

114 **Ells** (R. W.). Nicola coal basin, British Columbia.

Sum. Rept. Geol. Survey Canada, 1904, pp. 42–121, 1 pl., 2 figs., 2 maps.

Gives records of borings (pp. 70–74).

115 **Ely** (Charles W.), **Bennett** (Frank) and. Soil survey of Marshall County, Indiana.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 689–706, 1 map, 1 fig.

See Bennett (Frank) and Ely (Charles W.).

116 —— and **Griffin** (A. M.). Soil survey of Dodge County, Ga.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 231–246, 1 map, 1 fig.

Mentions the occurrence of sink holes (p. 235).

117 **Emmons** (Samuel Franklin). Copper in the Red Beds of the Colorado Plateau region.

Bull. U. S. Geol. Survey no. 260, pp. 221–232.

Contains brief references to the part of water in ore deposition.

118 —— The Cactus copper mine, Utah.

Bull. U. S. Geol. Survey no. 260, pp. 242–248.

Describes town water supply from Wawah springs, sixteen in number (p. 244).

119 —— Theories of ore deposition historically considered. (Presidential address, Geol. Soc. Am., 1903.)

Ann. Rept. Smithsonian Inst. for year ending June 30, 1904, pp. 309–336. Sci. Amer. Supp., vol. 60, no. 1563, pp. 25046–25047; no. 1564, pp. 25062–25064; no. 1565, pp. 25078–25079.

In reviewing the various theories of ore deposition, mentions the relations of deposition to circulation of underground waters, and water level, and the controversy regarding ascending and descending solutions, magmatic and meteoric waters, etc.

120 **Engineering and Mining Journal.** Geology at Simplon.

Eng. and Min. Jour., vol. 79, p. 180.

Notes the encountering in the Simplon tunnel in Switzerland and Italy of waters much hotter than had been predicted by geologists.

121 —— Water in the Egyptian Desert.

Eng. and Min. Jour., vol. 79, p. 812.

Notes the existence of a flowing-well area a few miles north of Kharga in which flows were obtained a few feet below the surface.

122 **Engineering and Mining Journal.** Banket in Rhodesia.

Eng. and Min. Jour., vol. 79, pp. 1236–1237.

Quotes H. D. Griffiths on the agency of underground waters in the enrichment of this gold-bearing conglomerate.

123 —— Gold in banket.

Eng. and Min. Jour., vol. 79, pp. 1241–1242.

Quotes the views of Schoch, Griffiths, Hatch, and Corstorphine as to the agency of underground waters in the enrichment of the gold-bearing conglomerates of the world.

124 —— A large pumping plant in Tasmania.

Eng. and Min. Jour., vol. 80, pp. 155–157, 4 figs.

Notes the encountering of large quantities of water in the Tasmania gold mine.

125 —— Gasolene pumps for irrigation.

Eng. and Min. Jour., vol. 80, p. 296.

Describes the effect of pumping on the water level in two 16-inch 45-foot wells at Garden, Kans.

126 —— Shaft sinking for salt. [Detroit, Mich.]

Eng. and Min. Jour., vol. 80, pp. 972–973, 1 fig.

Describes the encountering of large quantities of strong sulphur water.

127 —— The Simplon tunnel.

Eng. and Min. Jour., vol. 80, p. 1009.

Contains a description of the thermal springs encountered in the construction of the Simplon tunnel between Switzerland and Italy.

128 **Engineering News.** Vertical and lateral penetration of sewage bacteria into chalk soil.

Eng. News, vol. 53, pp. 116–117.

Describes experiments made near Amesbury, England.

129 —— Septic tanks and intermittent sand filters at Saratoga Springs, N. Y.

Eng. News, vol. 53, pp. 118–122.

Notes that the filtrate from the beds passes off through the ground without appreciably raising the water table (p. 122).

130 —— [The Simplon tunnel between Switzerland and Italy.]

Eng. News, vol. 53, pp. 229–230.

Describes the many springs of hot water encountered in the construction of this tunnel.

131 —— The Pennsylvania Railroad tunnel under Capitol Hill, Washington, D. C.

Eng. News, vol. 54, pp. 267–270.

Notes the penetration of quicksand carrying large quantities of water and describes the method used in draining the same (p. 267).

132 —— [Successful use of a divining rod.]

Eng. News, vol. 54, p. 386.

Notice of communication from Mr. G. Franzius, of the German Harbor Construction Bureau, in which is described the use of the divining rod in the location of wells at the Imperial Navy-Yard at Kiel. The geological conditions, the divining rod, and the tests made are briefly described.

133 **Engineering Record.** Air-lift pumping plant of the Redlands Water Company [California].

Eng. Rec., vol. 51, p. 8, 2 figs.; Compressed Air, vol. 10, pp. 3394–3396.

Contains a description of the wells furnishing the supply and the tests made to determine the effect of pumping on the ground-water level.

134 **Engineering Record.** Difficulty with the ground-water drains of a building.

Eng. Rec., vol. 51, p. 17.

Describes the inability of the underdrain of the New York Stock Exchange Building to handle ground water collecting below the cellar level. The drains were clogged by deposition from saturated drainage water. An analysis of the water is given.

135 —— Sewage disposal at Saratoga Springs, N. Y.

Eng. Rec., vol. 51, pp. 82–86, 6 figs.

Gives the level of the water table at the site of the sewage disposal plant as about 16 feet below the level of the original surface.

136 —— Legal restrictions on the use of underground-water supplies in New York.

Eng. Rec., vol. 51, pp. 177–178.

Complete description of the case of Frederick Reisert *v.* City of New York, and references to similar cases. The city operated a driven-well plant which influenced the value of cultivated ground by drying up a small surface stream and the city was therefore held responsible for damages.

137 —— A private irrigation system in Texas.

Eng. Rec., vol. 51, pp. 190–191, 5 figs.

Detailed description of the works is given. The principal source of supply is a spring with an unvarying flow of 70,000 gallons per minute.

138 —— The Simplon tunnel.

Eng. Rec., vol. 51, pp. 230–231.

Notes the encountering of large quantities of hot water in the construction of the tunnel between Switzerland and Italy.

139 —— Deep artesian wells in South Australia.

Eng. Rec., vol. 51, p. 332.

Notes the sinking of a 4,420-foot well with a flow of 600,000 gallons daily at a temperature of 204° F. Gives the total flow and cost of deep wells put down by the South Australian Government.

140 —— Measuring underflow.

Eng. Rec., vol. 51, p. 344.

Notes the use of Prof. C. S. Slichter's method of measuring underflow by Homer Hamlin at Los Angeles and in the San Francisco Valley. Several suggestions concerning the methods are made.

141 —— Irrigation in Texas.

Eng. Rec., vol. 51, pp. 60–61 of the Current News Supplement.

Describes the use of springs and artesian and surface wells in irrigation in Texas.

142 —— Difficulties with a pump well.

Eng. Rec., vol. 51, p. 384, 6 figs.

Describes the construction of a pump well and the sinking of several artesian wells at the Absecon pumping station of the Atlantic City, N. J., waterworks. The handling of a large volume of percolating water under high pressure was the chief difficulty.

143 —— [Damage from percolation.]

Eng. Rec., vol. 51, p. 412.

Notice of decision by appellate division of New York supreme court in Schwarzenbach *v.* Electric Water Power Company of Oneonta, 92 N. Y Sup., 187. The court ruled that percolation from the reservoir so as to flood the land of the plaintiff was unlawful, and that Schwarzenbach was entitled to damages.

144 —— The Asyut barrage across the Nile.

Eng. Rec., vol. 51, pp. 428–430, 2 figs.

Describes the occurrence of innumerable small springs in the bed of the foundation trench, the trouble caused by them, and the method used in sealing up the ventholes.

145 **Engineering Record.** [Artesian-well pumps at Memphis.]

Eng. Rec., vol. 51, p. 460.

Short notice of the use of special pumps for 64 wells at Memphis, Tenn.

146 —— Experimental work with wells at Battle Creek [Mich.].

Eng. Rec., vol 51, p. 502.

Describes the sinking of wells, the materials passed through, the flow, analyses of the water, and the effect of pumping on the level of the water table at Battle Creek, Mich. The Marshall sandstone is mentioned as containing water-bearing strata.

147 —— The First street tunnel, Washington [D. C.].

Eng. Rec., vol. 51, pp. 566–567, 8 figs.

Describes the encountering of water-bearing quicksand and the method of tunneling through it.

148 —— An unusual water main.

Eng. Rec., vol. 51, p. 581.

Describes the laying of a water main through beds of quicksand in Little Falls, N. Y. Dams were built every 300 feet, the water pumped out of the section, and the pipe laid, after which work was commenced on the next section.

149 —— Fire protection at the Worthington works.

Eng. Rec., vol. 51, pp. 684–685, 1 fig.

Describes the wells furnishing the water supply and the raising of the water by the air lift. [Harrison, N. J.]

150 —— Water supply by compressed air, Los Angeles, Cal.

Eng. Rec., vol. 52, p. 43 of the Current News Supplement.

Describes the water supply of Los Angeles from deep wells by means of compressed air.

151 —— Permeability experiments, North Dike, Wachusett reservoir. [Mass.]

Eng. Rec., vol. 52, p. 64.

Notes variations in the water table in the dike due to varying rainfall and seasonal changes; results show the dike to be nearly impermeable.

152 —— The waterworks at Raton, N. Mex.

Eng. Rec., vol. 52, p. 72.

The water supply is largely from springs; describes the building of trenches across the site of the dam to cut off the ground-water flow.

153 —— Sanitation in Manila.

Eng. Rec., vol. 52, pp. 76–79.

Notes the large amount of ground water which will infiltrate into the sewer pipes because of the laying of the latter at a considerable distance below sea level in a soil thoroughly saturated with water (p. 78).

154 —— Sliding hillsides.

Eng. Rec., vol. 52, p. 133.

Vibration, etc., of the railroad bridge upon which a water main is laid causes frequent leakage of the water, which results in the production of landslides.

155 —— [Developing underground water.]

Eng. Rec., vol. 52, p. 181.

Notes a decision of the California supreme court, 77 Pac. Rept. 1113, regarding the relation between owners of filtration tunnels and the owners of water flowing in a stream.

156 —— Improvements of the Elgin waterworks.

Eng. Rec., vol. 52, pp. 188–189.

Describes the deep-well water supply from the St. Peter and Madison sandstones at Elgin, Ill.

157 **Engineering Record.** Port Washington waterworks under air pressure.

Eng. Rec., vol. 52, pp. 205–206, 2 figs.

Describes the supplying of Port Washington, N. Y., with water from three 8-inch wells in gravel.

158 —— [A rock slide.]

Eng. Rec., vol. 52, p. 225.

Description of a slide in one of the quarries of the Lehigh Portland Cement Company, caused by the penetration of water along the contact of the limestone and cement rock.

159 —— Mechanical filters of the Brooklyn, N. Y., waterworks.

Eng. Rec., vol. 52, pp. 236–239, 4 figs.

Contains a description of the well and spring supply of Brooklyn.

160 —— An unusual system of wells.

Eng. Rec., vol. 52, p. 266.

Describes the waterworks system at Hastings, England. The water is obtained from three wells, 9 feet in diameter, two of the wells being 270 feet deep and the other 210 feet.

161 —— [Underground-water development in southern California.]

Eng. Rec., vol. 52, p. 266.

Notes the overdevelopment of the underground-water supply of this region.

162 —— Blowing wells.

Eng. Rec., vol. 52, p. 380.

Notes the investigation of this subject by the United States Geological Survey, and gives a brief explanation of the cause of the phenomenon.

163 —— The diminished yield of underground waters in southern California.

Eng. Rec., vol. 52, pp. 405–407.

Describes the geohydrologic conditions existing in this area and concludes that present diminished yield of underground water is due to an overdevelopment of the underground-water supply.

164 —— [Seepage from irrigation canals.]

Eng. Rec., vol. 52, p. 416.

Short discussion of the case of Howell *v.* Big Horn Basin Colonization Company, in Wyoming, in which the Wyoming supreme court decided that "seepage from irrigation canals is not only a waste of water, but may also result in the payment of damages for injury to property."

165 —— Sinking machinery foundations in quicksand without excavation.

Eng. Rec., vol. 52, p. 526.

Describes the method used in sinking through a bed of quicksand at Schenectady, N. Y., which prevented any subterranean flow from under adjacent footings.

166 —— The sewage pumping station at the Hampton Institute, Hampton, Va.

Eng. Rec., vol. 52, pp. 566–568, 4 figs.

Describes the relation between the sewage system and the high groundwater level at this place.

167 —— Difficult sewer construction in Minneapolis [Minn.].

Eng. Rec., vol. 52, pp. 639–640, 4 figs.

Describes the encountering of water-bearing quicksands and the methods used in working through them. Notes seepage of water into tunnel from the dumping ground.

168 —— The effect of seepage from ditches on stream flow.

Eng. Rec., vol. 52, p. 663.

Concludes that the use of water from the Platte River has reduced the size of the spring floods. Improvement in the flow of the stream is due to return seepage.

169 **Engineering Record.** Waterworks of Saugatuck, Mich.

Eng. Rec., vol. 52, pp. 665–666.

Detailed description of the water supply of this village, which is obtained from four wells driven along the bank of the Kalamazoo River.

170 —— [Artesian well.]

Eng. Rec., vol. 52, p. 725.

Describes the equipment of an artesian well 10 inches in diameter and 756 feet deep, belonging to the Fond du Lac Water Company, Wisconsin.

171 **Engineering Review.** Factory fire protection and water supply.

Eng. Review, vol. 15, no. 8, pp. 5–8, 7 figs.

Gives the location, depth, and material passed through of the wells furnishing the water supply at the Henry R. Worthington Hydraulic Works, Harrison, N. J. The water comes from a bed of gravel at a depth of about 400 feet.

172 **English Mechanic and World of Science.** A land of gold and marble.

Sci. Am. Supp., vol. 60, pp. 25034–25035.

Describes the limestone caverns and underground streams in New South Wales.

173 **Ensign** (O. H.). Power engineering applied to irrigation problem.

Water-Sup. and Irr. Paper no. 146, U. S. Geol. Survey, pp. 37–42.

Includes a statement concerning the practice of pumping from driven wells (p. 41).

F.

174 **Fairchild** (Herman Le Roy). Pleistocene features in the Syracuse region.

Am. Geologist, vol. 36, pp. 135–141.

Mentions occurrence of brines in drift in New York.

175 **Fenneman** (N. M.). The Florence, Colo., oil field.

Bull. U. S. Geol. Survey no. 260, pp. 436–440.

Notes occurrence of crevice encountered by an oil well which required two wagonloads of gravel to fill (p. 438), and discusses the number and limits of cracks and the occurrence of water in oil wells (p. 439).

176 —— Oil fields of the Texas-Louisiana Gulf Coast.

Bull. U. S. Geol. Survey no. 260, pp. 459–467.

Mentions the occurrence of salt water in oil wells of Texas (p. 460), tar springs and others emitting gas in Texas (pp. 462–463), and salt and sour waters (p. 464).

177 **Findley** (O. P.). Plant of the Cananea Consolidated Copper Company, Cananea, Sonora, Mexico.

Min. and Sci. Press, vol. 91, pp. 342–343, 4 figs.

The water supply comes from a well sunk to bed rock, with a subterranean gallery which taps an underground stream capable of furnishing 3,000,000 gallons per day.

178 **Finkle** (F. C.). Pumping underground water in southern California.

Water-Sup. and Irr. Paper no. 146, U. S. Geol. Survey, pp. 56–72.

Describes the underground reservoir in gravel (p. 57) and its replenishment from mountain streams and return waters from irrigation (p. 58). The extent of the supply (p. 59), its decline due to pumping (pp. 60–61), and the proposed replenishment by decreasing draft and constructing regulating works to secure distribution and absorption of waters of mountain streams are considered (pp. 61–63). Other points treated are laws relating to underground water (pp. 59–60) and pumping methods (pp. 63–72).

179 **Fischer** (Theobold). Morocco.

Ann. Rept. Smithsonian Inst. for year ending June 30, 1904, pp. 355–372. Trans. from Geographische Zeitschrift, Leipzig, February 12, 1903.

Mentions rarity of springs on the lower plain, and necessity for resorting to bored wells. Refers to salinity and unpalatableness of the water (p. 363).

180 **Fitzgerald** (William G.). A lost river.

Technical World Magazine, vol. 4, pp. 74–78, 3 figs.

Describes the great limestone cavern through which the river Lesse in Belgium passes in its subterranean course.

181 **Fleming** (Burton P.). Seepage investigations in the valley of the Laramie River.

Bull. Wyoming Exp. Sta. no. 61, 32 pp., 3 figs,

Discusses the causes, extent, and prevention of loss of water from canals by seepage, and reports the results of seepage measurements on Laramie River, Sand Creek, and a number of irrigation canals in Wyoming.

182 —— Irrigation work on the North Platte River.

Bull. Wyoming Exp. Sta. no. 66, 24 pp., 4 figs.

Gives measurements of seepage losses from canals in Wyoming and Nebraska (pp. 18–23).

183 **Fletcher** (R.). Disposal of household wastes at summer resorts, encampments, and farmhouses. Pure water supply and other sanitary conditions.

New Hampshire Sanit. Bull., July Supp., 23 pp., 8 figs. Abstract: Exp. Sta. Record, vol. 17, no. 4, p. 409.

Gives information regarding the construction of wells and their protection from contamination.

183a **Fogel** (Estelle D.), **Pammel** (L. H.) and. Some railroad water supplies.

Proc. Iowa Acad. Sci. for 1904, vol. 12, pp. 151–155.

See Pammel (L. H.) and Fogel (Estelle D.).

184 **Ford** (A. G.). Miscellaneous water analyses.

Bull. Oklahoma Agr. Exp. Sta. no. 67, 18 pp.

Gives chemical analyses of water from 95 wells and 13 springs, and states best locations for wells relative to houses, etc.

185 **Forestry and Irrigation.** Irrigation in Texas.

Forestry and Irrigation, vol. 11, pp. 230–231.

Describes the irrigation of portions of the State by water from surface and artesian wells.

186 —— The upbuilding of Nevada.

Forestry and Irrigation, vol. 11, pp. 270–274, 3 figs.

Mentions the sinking of mountain streams in the sands of the desert.

187 **Fortier** (S.). Irrigation in Santa Clara Valley, California.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, pp. 77–91.

Mentions use of wells for irrigation in this valley and describes methods of applying water.

188 **Franke** (Robert P.). Geology of the Cochise mining district, Arizona.

Min. Reporter, vol. 51, p. 503, 1 fig.

Notes that the descending waters have leached great portions of the beds.

189 **Fuller** (Myron Leslie). Artesian flows from unconfined sandy strata.

Eng. News, vol. 53, pp. 329–330, 2 figs.

Describes examples on Long Island, New York, and in Michigan, and offers an explanation of the cause.

190 **Fuller** (Myron Leslie). The measurement of low aresian heads.

Eng. News, vol. 53, p. 593, 1 fig.

Describes a small gage for taking artesian-well pressures.

191 —— Some results of Geological Survey work in the location of underground waters.

Eng. News, vol. 54, p. 517.

A letter to the editor of the Engineering News, in which Mr. Fuller notes the fulfilling of predictions made by Mr. W. H. Norton as to the underground waters at Waterloo, Iowa.

192 —— Geology of Fishers Island, New York.

Bull. Geol. Soc. America, vol. 16, pp. 367–390.

Gives well record and describes lateral transmission of water through joints of crystalline rocks from mainland, 7 miles distant (p. 372).

193 —— Objects, development, and results of the work of collecting well records and samples.

Bull. U. S. Geol. Survey no. 264, pp. 12–39.

Discusses the importance and benefit of well records, and describes the organization of the division of hydrology and the methods of collecting samples and records. Among the points incidentally considered are the occurrence of oil, gas, and water (p. 12), factors affecting well drilling (p. 13), use of records (p. 14), problems of depth, character of materials, water supplies, casing, limits of depth, location of oil and gas shows, head, and use of water for industrial, irrigation, medicinal and bathing purposes, and at resorts (pp. 15–20).

194 —— Introduction.

Contributions to the hydrology of eastern United States, 1904; Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 9–16.

Summarizes papers included in the report.

195 —— Triassic rocks of the Connecticut Valley as a source of water supply.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 95–112, 8 figs.

Discusses the occurrence of water in Triassic conglomerates, sandstones, shales, and traps; and the influence of structure, jointing, and faulting on the waters. Discusses the testing of wells, keeping of accurate records, and the proper depth of wells. Gives analyses.

196 —— Notes on the hydrology of Cuba.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 183–199.

Describes the various town and city supplies obtained from ordinary and artesian wells, underground streams, and springs (pp. 187–193). Describes wells sunk by U. S. War Department (pp. 196–199), and gives record (p. 192) and analysis (p. 198). Discusses abundance of springs and mentions submarine springs (pp. 193–194). Describes subterranean streams and their relation to limestone caves (p. 194). Discusses mineral waters and gives analyses (pp. 194–196).

197 —— Occurrence of underground waters.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 18–40, 4 pls., 14 figs.

Describes sources of ground water, relation to rainfall, permeability and storage capacity of rocks, occurrence and amount of water, types of water-bearing formations, temperature of underground waters, and their recovery by seepage, springs, and by wells. Gives a short chapter on artesian flows, enumerating the essential conditions. Describes briefly the underground-water conditions of eastern United States, including types of rock and rock-water provinces.

198 —— New Hampshire.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 57–59.

Summarizes data regarding wells and springs, and enumerates 8 commercial springs.

199 **Fuller** (Myron Leslie). Pennsylvania.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 104–110, 1 fig.

Describes distribution of wells in the drift, stream deposits, crystalline rocks, Triassic, Cambrian, Silurian, Devonian, and Carboniferous rocks, and Coastal Plain deposits. Enumerates mineral springs, and gives principal publications on underground waters of the State.

200 —— North Carolina.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 136–139, 1 fig.

Describes briefly the artesian conditions of the Coastal Plain and the occurrence of water in the Potomac formation, and gives list of wells. Describes briefly the occurrence of water in the Piedmont Plateau and Appalachian Mountain belt. Lists the principal mineral springs and publications on underground waters of the State.

201 —— Florida.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 159–163, 1 fig.

Describes underground-water conditions of the highland area and the artesian areas of the west and east coasts. Mentions driven wells in the sand area. Notes several mineral springs and publications on water conditions of the State.

202 —— Lower Michigan.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 242–247, 2 figs.

Compiles data regarding the underground-water resources of the Lower Peninsula of Michigan. Lists the principal publications and notes important mineral springs.

203 —— West Virginia.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 271–272.

Summarizes the conditions bearing on underground-water supplies in the Appalachian Mountain belt and the Cumberland Plateau. Lists the principal mineral springs of the State.

204 —— Bibliographic review and index of papers relating to underground waters published by the United States Geological Survey, 1879–1904.

Water-Sup. Paper no. 120, U. S. Geol. Survey, 128 pp.

Lists all references to underground waters, springs, well records, and drilling methods, and gives detailed classified subject index.

205 —— Hydrologic work in eastern United States and publications on ground waters.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 9–29.

Describes the organization of the division of hydrology and gives an account of the work of the eastern section in 1904. The special work included the collection of well records and samples, the preparation of bibliographies and hydrologic tables, and a study of the relation of the law to underground waters. About 50 geologists were employed during the year, work being conducted in Maine, New Hampshire, Massachusetts, New York, New Jersey, Maryland, Virginia, West Virginia, Georgia, Alabama, Mississippi, Tennessee, Kentucky, Arkansas, Louisiana, Missouri, Iowa, Minnesota, Wisconsin, and Michigan. The paper contains a summary of the other papers in the report and gives a list of survey publications relating to underground waters.

206 —— Two unusual types of artesian flow.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 40–45.

Describes flows from uniform unconfined sands taking place in virtue of lamellar arrangement of elongated sand grains on Long Island, New York, and in Michigan. The lateral transmission of water through joints in stratified rocks for long distances independently of structure in southeastern Michigan is also described. The confinement necessary for the flow is afforded by the clayey drift overlying the more porous rock.

207 **Fuller** (Myron Leslie). Construction of so-called fountain and geyser springs.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 46–50.

Differentiates confined and unconfined springs, and gives methods by which the former can be converted into a "fountain," and both into intermittent or geyser springs.

208 —— A convenient gage for determining low artesian heads.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 51–52.

Describes a 2-inch nickel gage which, by means of a rubber flange, can be instantly applied to pipes up to 2 inches in diameter and will read pressures up to 50 pounds.

209 —— A ground-water problem in southeastern Michigan.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 129–147.

Discusses the failure of wells along Huron River. The water occurs in the jointed upper portion of the Dundee limestone and Monroe and Sylvania sandstones, in which it is confined by overlying glacial clays. The loss of head and flow are described and the causes, including the effect of adjacent deep wells, quarrying operations, deforestation, ditching, frost, and deficiency of rainfall are considered. Deforestation and ditching are the most far-reaching causes, but an early frost which froze the ground and prevented the absorption of late autumn rains of the previous year, in connection with low rainfall, was the more immediate cause.

210 —— Notes on certain large springs of the Ozark region, Missouri and Arkansas.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 207–210.

Outlines the geologic conditions and describes and gives discharge of Greer, Van Buren, Fanchon, Alley, Blue, Mesamer, and Boiling springs of Missouri and the Mammoth spring of Arkansas.

211 —— Failure of wells along the lower Huron River, Michigan, in 1904.

Ann. Rept. Michigan Geol. Survey for 1904, pp. 7–29, pl. 1, figs. 1 and 2.

Describes the relations and conditions of the wells, and ascribes their decline to the deforesting and ditching of the region and an early frost followed by a dry summer. Advocates the passing of laws regulating deep or artesian wells.

212 —— Cause and period of earthquakes in the New Madrid area, Missouri and Arkansas.

Abstract: Science, new. ser., vol. 21, pp. 349–350.

Notes settling of the surface in this area due to undermining by ground waters under artesian pressure.

213 —— Artificial fountain and geyser springs.

Sci. Am., vol. 93, p. 67, 4 figs.

Discusses the geological conditions resulting in the formation of springs and the artificial construction of fountain and geyser springs.

214 —— **Darton** (N. H.) and. Maryland.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 114–123, 2 pls.

See Darton (N. H.) and Fuller (Myron Leslie).

215 —— **Darton** (N. H.) and. District of Columbia.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 124–126, 1 pl.

See Darton (N. H.) and Fuller (Myron Leslie).

216 —— **Darton** (N. H.) and. Virginia.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 127–135, 1 pl.

See Darton (N. H.) and Fuller (Myron Leslie).

217 **Fullerton** (Aubrey). A new mammoth cave.

Technical World Magazine, vol. 4, pp. 206–208, 6 figs.

Describes an immense cave in the limestone of Cougar Mountain, in the Selkirks of British Columbia, and the streams flowing in it.

G.

218 **Gale** (Hoyt S.). Water resources of the Cowee and Pisgah quadrangles, North Carolina.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 174–176.

Describes the abundance of good springs, with a few chalybeate and sulphur springs. Describes the association of carbonate springs with hornblendic gneiss and of chalybeate waters with pyrite deposits along faults. Mentions the rarity of wells in the area.

219 **Garry** (G. H.), **Spurr** (J. E.) and. Preliminary report on ore deposits in the Georgetown, Colo., mining district.

Bull. U. S. Geol. Survey no. 260, pp. 99–120.

See Spurr (J. E.) and Garry (G. H.).

220 **Geib** (W. J.), **Rice** (Thomas D.) and. Soil survey of the Gainesville area, Florida.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 269–289, 1 map, 1 fig.

See Rice (Thomas D.) and Geib (W. J.).

221 —— **Rice** (Thomas D.) and. Soil survey of Warren County, Kentucky.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 527–541, 1 map, 1 fig.

See Rice (Thomas D.) and Geib (W. J.).

222 **George** (H. C.). A freak oil field.

Eng. and Min. Jour., vol. 80, pp. 876–877.

Describes the "Grasshopper oil field" of Warren, Pa. The oil occurs as a scum on the surface water in the glacial deposits. Notes the rising and falling of the water level in the wells with the water of the river.

223 **Gerhard** (William Paul). The water supply of country buildings, Part I.

Cassier's Magazine, vol. 27, pp. 482–498, 14 figs.

Detailed discussion of wells, springs, and collecting galleries as sources of supply. Some of the figures show method of arranging well batteries.

224 **Getman** (F. L.). The new artesian water supply of Ithaca, N. Y.

Eng. News, vol. 53, pp. 412–414, 4 figs.

Describes the local geology, sinking of wells, details of equipment, and cost of construction.

225 **Gieseler** (E. A.). A new form of filter gallery at Nancy, France.

Eng. Rec., vol. 51, pp. 148–149, 5 figs.

Describes the construction of a filter gallery parallel to the river Moselle, designed to collect the subsoil water.

226 **Glenn** (L. C.). South Carolina.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 140–152, 1 pl.

Describes briefly the distribution of springs and enumerates those of commercial value (pp. 141–142). Discusses distribution of open and deep wells, and their relations (pp. 142–144, 151–152). States the water conditions in the crystalline rocks, the Potomac formation, the marine Cretaceous beds, Eocene, Miocene, Lafayette, and Columbia deposits (pp. 146–149). Gives table of deep wells with statistics (pp. 149–151). Lists the principal publications on underground water of the State (p. 152).

227 —— Tennessee and Kentucky.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 198–208.

Decribes the underground-water resources of the valley of East Tennessee, the Cumberland Plateau, the Highland and Lexington Plains, and the Gulf Coastal Plain. Lists the important mineral springs and the principal publications on underground waters of the two States.

228 **Goodell** (Edwin B.). A review of the laws forbidding pollution of inland waters in the United States, second edition.

Water-Sup. and Irr. Paper no. 152, U. S. Geol. Survey, 149 pp.

Many of the enactments include laws against the pollution of wells and springs, as well as surface streams.

228a **Gould** (Charles Newton). Geology and water resources of Oklahoma.

Water-Sup. and Irr. Paper no. 148, U. S. Geol. Survey, 173 pp., 22 pls., 32 figs.

Describes gypsum caves (pp. 52, 98), sink holes (p. 74), brine springs (pp. 41, 100–104), sulphur springs (pp. 104–105), and the occurrence of salt water in wells (pp. 106–107). Describes the artesian conditions, by counties (pp. 109–133). Gives detailed statistics regarding a number of deep wells (pp. 105–106) and records (pl. XXII), and describes the occurrence of underground water in granite, porphyry, the Arbuckle limestone, Whitehorn sandstone, Greer formation, Quartermaster formation, conglomerate, and in red beds and alluvium (pp. 95–100). Describes underflow of streams (p. 90). Classifies and describes the springs of the Territory (pp. 94–105), and discusses the use of springs for public supply (p. 99) and irrigation (pp. 139–140). Discusses the use of well waters for irrigation (pp. 140–141). Gives an appendix containing many analyses of wells (pp. 143–149) and springs (p. 153) and statistics regarding location, size, depth, method of pumping, quality of water, discharge, and geological relations of 261 wells.

229 **Grant** (U. S.). Water resources of the Mineral Point quadrangle, Wisconsin.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 67–73.

Gives a geologic section and discusses underground-water conditions. Good springs occur at the outcrop of the Galena and Platteville limestones and the St. Peter sandstone, while drilled wells obtain good supplies from the Galena limestone and St. Peter and Potsdam sandstones.

230 **Gregory** (H. E.). Connecticut.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 76–81, 1 fig.

Describes underground-water conditions in the limestone area, Triassic sandstone area, and the crystalline areas. Notes the relation of faults to water supply. Discusses springs and wells obtaining water in the drift. Enumerates mineral springs and gives list of publications.

231 **Gregory** (John H.). The Scioto River storage dam at Columbus, Ohio.

Eng. Rec., vol. 52, pp. 302–305, 4 figs.

Describes the well and filtering gallery or conduit system now in use at Columbus.

232 **Gregory** (J. W.). Rio Tinto, Spain.

Eng. and Min. Jour., vol. 79, pp. 370–372, 4 figs.

Contains a discussion of the agency of underground waters in the formation of the copper deposits at this place.

233 —— The ore deposits of Mount Lyell. [California.]

Min. and Sci. Press, vol. 91, (pp. 75–76, 90–91).

These two articles are devoted mainly to a discussion of the agency of water in the genesis of these deposits.

234 **Griffin** (A. M.), **Bennett** (Frank) and. Soil survey of the Orangeburg area, South Carolina.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 185–205, 1 map, 1 fig.

See Bennett (Frank) and Griffin (A. M.).

235 —— **Ely** (Charles W.) and. Soil survey of Dodge County, Ga.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 231–246, 1 map, 1 fig.

See Ely (Charles W.) and Griffin (A. M.).

236 **Griffin** (A. M.), **Hearn** (W. Edward) and. Soil survey of the Alma area, Michigan.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 639–664, 1 map, 1 fig.

See Hearn (W. Edward) and Griffin (A. M.).

237 **Griswold** (Lewis), **Rice** (Thomas D.) and. Soil survey of Acalia Parish, Louisiana.

Field Operations of the Bureau of Soils, 1903, U. S. Dept. Agr., pp. 461–485, 1 fig., 1 map.

See Rice (Thomas D.) and Griswold (Lewis).

238 **Gunther** (Charles Godfrey). The gold deposits of Plomo, San Luis Park, Colorado.

Econ. Geol., vol. 1, pp. 143–154.

Considers part played by circulating ground waters in deposition of ores along fissures and faults (p. 153).

239 —— An interesting fault system [California].

Eng. and Min. Jour., vol. 80, p. 1013, 1 fig.

Contains a description of the manner in which the ore-bearing solutions passed along the faults.

240 **Gilbert** (Grove Karl). Plans for obtaining subterranean temperatures.

Year Book no. 3, 1904, Carnegie Institution of Washington, pp. 259–260.

Gives estimate of cost of drilling to various depths and makes recommendations.

241 —— Value and feasibility of a determination of subterranean temperature gradient by means of a deep boring.

Year Book no. 3, 1904, Carnegie Institution of Washington, pp. 261–267. Abstract, p. 120.

Considers need for such a determination, conditions to be satisfied in the selection of a site for a boring, and concludes that the Lithonia district, Georgia, is preferable.

242 **Goding** (F. W.). Queensland artesian wells.

Daily Consular Repts. no. 2166, Dept. Com. and Labor, pp. 6–7.

Gives statistics regarding average depth, flow, temperature, etc., of the 960 wells in the State.

243 **Greeley** (W. B.). The effect of forest cover upon stream flow.

Forestry and Irrigation, vol. 11, pp. 163–168, 309–315, 4 figs.

Discusses the absorption of rainfall by the soils, the effect of underground seepage on stream flow; and, in the second article (pp. 309–315), describes an investigation of certain areas in New York.

H.

244 **Hale** (Harrison). Analyses: Waters from Oklahoma and Indian Territories.

Bull. Bradley Geol. Field Sta. Drury Coll., vol. 1, pt. 2, pp. 100–102.

Gives the results of examination of a considerable number of well waters to determine suitability for boiler purposes.

245 **Hall** (B. M.). Rio Grande project.

Water-Sup. and Irr. Paper no. 146, U. S. Geol. Survey, pp. 75–78.

Notes insufficiency of underflow and inapplicability of submerged dams (pp. 76–77).

246 —— Past and present plans for irrigation of the Rio Grande Valley.

The official proceedings of the Twelfth National Irrigation Congress, at El Paso, Tex., November 15–18, 1904, pp. 213–221.

Discusses underflow of the Rio Grande Valley as a source of supply for wells (pp. 216–218).

247 **Hall** (Charles M.) and **Willard** (Daniel E.). Description of Casselton and Fargo quadrangles. [North Dakota and Minnesota.]

Geologic Atlas U. S., folio 117, U. S. Geol. Survey, 7 pp.

Gives well logs and statistical data (pp. 5-6), describes springs and drift and artesian wells (p. 4), and the source (probably from Dakota sandstone) and character of the deep waters. An artesian well section showing drift and Cretaceous horizons (p. 2) and maps showing flowing and nonflowing areas in drift and older formations, head, depth of wells, etc., are also given.

248 **Hall** (Christopher Webber). Minnesota.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 226–232, 1 fig.

Describes the underground-water resources of the Cambrian, Ordovician, Cretaceous, and Quaternary rocks of the State. Describes the artesian basins and gives a map showing their distribution. Notes the principal mineral springs, and describes the distribution of springs in general. Lists the principal publications referring to underground waters of the State.

249 **Hall** (M. R.) and **Hoyt** (John C.). Report of progress of stream measurements for the calendar year 1904: Part IV, Santee, Savannah, Ogeechee, and Altamaha rivers and eastern Gulf of Mexico drainages.

Water-Sup. and Irr. Paper no. 128, U. S. Geol. Survey, 168 pp.

Gives description and discharge of Blue (p. 120) and Cave (p. 175) springs, Georgia.

250 —— **Johnson** (E., jr.), and **Hoyt** (John C.). Report of progress of stream measurements for the calendar year 1904: Part V, Eastern Mississippi River drainage.

Water-Sup. and Irr. Paper no. 128, U. S. Geol. Survey, 168 pp.

Describes and gives discharge of Big Springs, Alabama (p. 152).

251 **Halse** (Edward). The occurrence of pebbles, concretions, and conglomerate in metalliferous veins.

Bimonthly Bull. Am. Inst. Min. Eng. no. 4, pp. 719–742, 13 figs.

Contains a description of the agency of waters percolating along fracture planes in the decomposition of rocks and giving rise to concentric structures which subsequently become rounded by attrition, and are finally cemented together by the aid of mineralized thermal solutions.

252 **Hamlin** (Homer). Underflow tests in the drainage basin of Los Angeles River.

Water-Sup. and Irr. Paper no. 112, U. S. Geol. Survey, 55 pp.

Discusses the occurrence of ground waters, nature of water table, and fluctuations and movements of the water body (pp. 9–11). Describes underflow tests including location of wells, methods of driving and drilling, machinery and materials, well points, underflow meter, charging of wells, measurement of velocity, etc. (pp. 11–29), and gives summary (p. 53). Porosity, packing, and capacity of sediments are considered (pp. 29–31), and records of actual tests given in detail (pp. 33–53). Many local well records are given by diagram.

253 **Hammond** (G. A.). Diamond-drill methods.

Water-Sup. and Irr. Paper no. 146, U. S. Geol. Survey, pp 78–80.

Describes apparatus and methods of work under different conditions.

254 **Haney** (J. G.). Irrigation experiments at Fort Hays, Kans., 1903 and 1904.

Bull. Office Exp. Sta., U. S. Dept. Agr., no 158, pp. 567–583.

Describes experiments in using wells for irrigation; discusses methods of drilling and pumping and cost of wells, and relations to geology.

255 **Hanna** (F. W.). The irregular flow of rivers in humid prairie States.

Eng. News, vol. 54, pp. 118–119.

Pasturage, drainage, and cultivation has resulted in an increase of the amount of rainfall running off from the surface and a decrease in the amount of ground water which escapes into the streams, and, therefore, causing great irregularity in the flow of the rivers.

256 **Harris** (Gilbert D.). Underground waters of southern Louisiana.

Bull. Louisiana Geol. Survey no. 1, pp. 1–77, 7 pls., 12 figs.

Discusses the origin of the artesian and deep-well waters, gives detailed well statistics, discusses variation in flow and pressure head, methods of well drilling and pumping, and gives records and analyses.

257 **Harrison** (Virginius). Mineral waters.

Bull. Virginia Hosp., vol. 1, no. 3, pp. 41–45.

Discusses briefly the origin of mineral waters and the origin of thermal springs; gives Crook's classification according to composition, and outlines their therapeutic uses.

258 **Harroun** (Philip E.). The waterworks of Porterville, California.

Trans. Am. Soc. Civil Eng., vol. 54, pp. 235–279, pls. 19 and 20, 5 figs.

Describes the wells furnishing the water supply as to size, depth, location, materials passed through, etc. Describes leakage of oil from fuel-oil storage tank, resulting in contamination of the ground water and consequent pollution of the city's supply. In the discussion attached to this article H. F. Dunham discusses the pollution of well waters and Mr. Harroun describes the Herron perforator for perforating well casings in place.

259 **Hatch** (Frederick H.) and **Corstorphine** (George S.). The origin of the Witwatersrand gold. [Transvaal.]

Eng. and Min. Jour., vol. 79, pp. 80–81.

Discusses the agency of underground water in formation of the auriferous deposits.

260 **Hatcher** (J. B.), **Stanton** (Timothy W.) and. Geology and paleontology of the Judith River beds.

Bull. U. S. Geol. Survey no. 257, pp. 1–66.

See Stanton (Timothy W.) and Hatcher (J. B.).

261 **Haworth** (Erasmus), **Schrader** (F. C.) and. Oil and gas of the Independence quadrangle, Kansas.

Bull. U. S. Geol. Survey no. 260, pp. 446–458.

See Schrader (F. C.) and Haworth (Erasmus).

262 **Hayes** (C. Willard). Contributions to economic geology, 1904; introduction.

Bull. U. S. Geol. Survey no. 260, pp. 11–18.

Gives list of folios containing discussions of underground and artesian waters, mineral springs, etc.

263 **Hazelhurst** (J. N.). Sanitary engineering in the South and the labor question.

Eng. News, vol. 54, pp. 294–295; Municipal Engineering, vol. 29, pp. 249–252.

Notes the difficulty of construction of sewage-discharge works at New Orleans due to the complete saturation of the ground at all points beneath the surface; considerable attention is given to the subject of infiltration of ground water into the sewer pipes and the danger of overcharging the same by excessive infiltration of ground water.

264 **Headden** (William P.). The Doughty Springs, a group of radium-bearing springs on the North Fork of Gunnison River, Delta County, Colorado.

Proc. Colorado Sci. Soc., vol. 8, pp. 1–30, 6 pls.

A very complete description of the location, geology, deposits, flow, composition of the water (many analyses being given), temperatures, etc., of these springs. Describes the deposition of barium sulphate from the spring water. Describes the tests made to show the presence of radium in the deposits of the springs, and reproduces several photographs showing the action upon photographic plates of the sinter deposited by the springs.

265 —— Mineralogical notes, no. II.

Proc. Colorado Sci. Soc., vol. 8, pp. 55–70.

Discusses the origin of the aluminum sulphate occurring in the Alum Spring, Delta County, Colo., and gives analyses of deposits of alunogen occurring in the vicinity of the springs (pp. 62–66). Gives a description and analysis of a hydrated basic aluminic sulphate deposited by the action of alkaline spring waters upon spring waters carrying aluminic sulphate in solution at Doughty Springs, Delta County, Colo. (pp. 66–67).

266 **Hearn** (W. Edward) and **Carr** (M. E.). Soil survey of the Biloxi area, Mississippi.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 353–374, 1 map, 1 fig.

Mentions flowing artesian wells in the area (pp. 358–359).

267 —— and **Griffin** (A. M.). Soil survey of the Alma area, Michigan.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 639–664, 1 map, 1 fig.

Mentions occurrence of artesian and ordinary wells, and depths to water (p. 644).

267a **Henderson** (C. R.), **Maury** (Dabney H.), **Burdick** (C. B.), and. Report of the committee on waterworks.

Twentieth Ann. Rept. Illinois Soc. Eng. and Surv., pp. 132–139.

See Maury (Dabney H.), Burdick (C. B.), and Henderson (C. R.).

268 **Hill** (John W.). The Torresdale conduit [Philadelphia, Pa.].

Jour. Franklin Institute, vol. 159, pp. 241–297, pls. 1–30. Also in Proc. Eng. Club of Phila., vol. 22, pp. 129–189.

Describes the encountering of water in diamond-drill borings and in rock and gravel excavations along the line of the conduit; discusses the level of ground water, the leakage of ground water into the sewer, the head and leakage of ground water in the case of the Jersey City conduit and several conduits in New York State; discusses briefly the analyses of the rock and ground waters encountered (no analyses given).

269 **Hill** (Robert T.). El Oro district, Mexico.

Eng. and Min. Jour., vol. 79, pp. 410–413, 11 figs.

Contains a discussion of the agency of mineral-bearing solutions in the formation of the deposits.

270 —— Source of volcanic water.

Eng. and Min. Jour., vol. 80, pp. 13–14, 4 columns.

Discusses two theories: (1) That the volcanoes are fed by infiltration of surface waters, and (2) that the water is derived from the gases of the earth's interior.

271 —— Pelé and the evolution of the Windward Archipelago.

Bull. Geol. Soc. America, vol. 16, pp. 243–288.

Mentions the occurrence of warm springs (p. 248), and notes the part of water in ore deposition (p. 278); describes the products of eruptions and the discharge of water vapor (pp. 250, 271); considers the part of water in producing eruptions (pp. 280, 281, 287); ascribes an origin of the water of vulcanism from interior gases (p. 284), and quotes Geikie (p. 286) and Suess (p. 288) on the magmatic origin of waters of hot springs and volcanoes.

272 **Hinderlider** (M. C.) and **Hoyt** (John C.). Report of progress of stream measurements for the calendar year 1904: Part VIII, Platte, Kansas, Meramec, Arkansas, and Red River drainages.

Water-Sup. and Irr. Paper no. 131, U. S. Geol. Survey, 203 pp.

Describes and gives discharge of Greer (p. 178) and Meramec springs (p. 123) in Missouri.

273 —— **Swendsen** (G. L.), and **Chandler** (A. E.). Report of progress of stream measurements for the calendar year 1904: Part X, Colorado River and the Great Basin drainages.

Water-Sup. and Irr. Paper no. 133, U. S. Geol. Survey, 384 pp.

Gives discharge of Big Springs, Utah (p. 364), Heitmans and Monfrena springs, Nevada (p. 358), and describes seepage investigations in Arizona (p. 48).

274 **Hitchcock** (A. S.). Alfalfa growing.

Farmers' Bull. no. 215, U. S. Dept. Agr., 39 pp., 8 figs.

Describes irrigation of alfalfa by artesian wells, streams, etc., (pp. 20–22).

275 **Hitchcock** (C. H.). Fresh-water springs in the ocean.

Pop. Sci. Monthly, vol. 67, pp. 673–683, 3 figs.

Describes the underground waters of the Hawaiian Islands, Cuba, and Florida, and the occurrence of fresh-water springs in the ocean off the coast of these places.

276 **Hixon** (Hiram W.). Geology of the Sudbury district.

Eng. and Min. Jour., vol. 79, pp. 334–335, 1 fig.

Letter to the editor in reply to article of A. P. Coleman. Defends his statements that the nickel ores of this district were deposited from underground waters.

277 —— Volcanoes and earthquakes.

Eng. and Min. Jour., vol. 79, p. 1245.

The author ascribes these phenomena to the escape of the water of combination held in the igneous core of the earth.

278 —— The Sudbury district.

Eng. and Min. Jour., vol. 80, pp. 116–117.

Discusses the agency of heated thermal waters from igneous magmas in the formation of ore deposits, and quotes C. V. Corless to show the origin of the Sudbury deposits to be due to deposition from mineralizing solutions.

279 **Hobbs** (William Herbert). Origin of the channels surrounding Manhattan Island, New York.

Bull. Geol. Soc. America, vol. 16, pp. 151–182.

Gives several sections based on borings.

280 —— The configuration of the rock floor of Greater New York.

Bull. U. S. Geol. Survey no. 270, 96 pp., 5 pls., 6 figs.

Compiles 1,424 records of wells and borings, giving depths to bed rock and occasionally more complete records.

281 **Hollister** (George B.). Waters of a gravel-filled valley near Tully, N. Y.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 179–184.

Describes the occurrence and composition of the ground waters of a deep valley deposit of glacial gravels, and gives analyses of spring waters. The deposits are typical of their kind, and occur at many points in New York and New England. The discharge and tufa deposits of the springs are also described.

282 **Holmes** (J. Garnett) and **Neill** (N. P.). Soil survey of the Greeley area, Colorado.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 951–993, 1 map, 1 fig.

Discusses briefly the relation of underground and seepage waters to irrigation (pp. 983–984).

283 —— and others. Soil survey of the Yuma area, Arizona-California.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 1025–1047, 2 maps, 1 fig.

Discusses briefly the occurrence of underground and seepage waters and their effect on alkali (p. 1043).

284 —— and others. Soil survey of the San Bernardino Valley, California.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 1115–1151, 1 map, 1 fig.

Describes the geologic occurrence of artesian water and "pumped water" in gravel (pp. 1122–1123), and use for irrigation (pp. 1142–1143). Discusses seepage waters and injurious effect on agricultural conditions (pp. 1141–1142).

285 **Horton** (Robert E.). The drainage of ponds into drilled wells.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 30–39.

Describes the drainage of ponds and swamps in kettle holes, etc., of the drift regions of Michigan into drilled wells, and discusses the underground conditions, methods, cost, and capacity of the wells, and gives examples of their successful application.

286 —— Importance of general hydrographic data concerning basins of streams gaged.

Water-Sup. and Irr. Paper no. 146, U. S. Geol. Survey, pp. 87–89.

Points out necessity of knowledge of soils and rocks and their absorptive capacities.

287 **Hove** (A. M.). The Pecos Valley [Texas and New Mexico].

Forestry and Irrigation, vol. 11, pp. 433–435, 2 figs.

Mentions the use of artesian-well water in irrigation, and a photograph given shows an artesian well in New Mexico with a flow of 3,000 gallons a minute.

288 **Hovey** (Edmond Otis). The western Sierra Madre Mountains.

Science, new ser., vol. 21, pp. 585–587.

Mentions shallow wells which obtain water from underground water courses for copper smelters at Douglas, Ariz. (p. 586.).

289 **Hovey** (Horace C.). Strange mazes and chasms in Mammoth Cave.

Sci. Am. Supp., vol. 60, pp. 24680–24681, 2 figs.

Description of explorations made in 1859, 1863, and 1905 in Mammoth Cave, Kentucky.

290 **Howarth** (O. H.). Vein structure.

Mines and Minerals, vol. 25, pp. 369–371, 5 figs.

Discusses the agency of underground water in the formation of veins.

291 **Hoyt** (John C.), **Babb** (Cyrus C.) and. Report of progress of stream measurements for the calendar year 1904; Part VII, Hudson Bay, Minnesota, Wapsipinicon, Iowa, Des Moines, and Missouri River drainages.

Water-Sup. and Irr. Paper no. 130, U. S. Geol. Survey, 204 pp.

See Babb (Cyrus C.) and Hoyt (John C.).

292 **Hoyt** (John C.), **Hall** (M. R.) and. Report of progress of stream measurements for the calendar year 1904; Part IV, Santee, Savannah, Ogeechee, and Altamaha rivers and Eastern Gulf of Mexico drainages.

Water-Sup. and Irr. Paper no. 127, U. S. Geol. Survey, 192 pp.
See Hall (M. R.) and Hoyt (John C.).

293 —— **Hall** (M. R.), **Johnson** (E., jr.) and. Report of progress of stream measurements for the calendar year 1904; Part V, Eastern Mississippi River drainage.

Water-Sup. and Irr. Paper no. 128, U. S. Geol. Survey, 168 pp.
See Hall (M. R.), Johnson (E., jr.), and Hoyt (John C.).

294 —— **Hinderlider** (M. C.) and. Report of progress of stream measurements for the calendar year 1904; Part VIII, Platte, Kansas, Meramec, Arkansas, and Red River drainages.

Water-Sup. and Irr. Paper no. 131, U. S. Geol. Survey, 203 pp.
See Hinderlider (M. C.) and Hoyt (John C.).

295 —— **Taylor** (T. U.) and. Report of progress of stream measurements for the calendar year 1904; Part IX, Western Gulf of Mexico and Rio Grande drainages.

Water-Sup. and Irr. Paper no. 132, U. S. Geol. Survey, 132 pp.
See Taylor (T. U.) and Hoyt (John C.).

296 —— and **Wood** (B. D.). Index to the hydrographic progress reports of the United States Geological Survey, 1888–1903.

Water-Sup. and Irr. Paper no. 119, U. S. Geol. Survey, 253 pp.
This is a place index, and although the discharges of a number of springs are given they can be found only when name of spring is known.

297 **Hulbert** (H. B.). The Island of Quelpart [Asia].

Bull. Am. Geog. Soc., vol. 37, pp. 396–408, 1 fig.
Mentions the occurrence of a mountain spring known as the "Bushel well," and gives a legend relating to it.

298 **Huntington** (Ellsworth). The depression of Sistan, in eastern Persia.

Bull. Am. Geog. Soc., vol. 37, pp. 271–281, 2 figs.
Notes the location of wells in dry stream beds where the water was only a few feet below the surface (p. 276).

299 —— The mountains and kibitkas of Tian Shan [Asia].

Bull. Am. Geog. Soc., vol. 37, pp. 513–530, 2 figs.
Describes the occurrence of springs and ascribes their origin to water under artesian pressure in glacial gravels. A figure is given to show the conditions.

300 —— A geologic and physiographic reconnaissance in central Turkestan.

Explorations in Turkestan, with an account of the basin of eastern Persia and Sistan—Carnegie Institution of Washington, pp. 157–216, 29 figs.
Notes numerous large springs from gravel in Bokhara (pp. 180–181). Describes springs near Shor Kul and explains the artesian conditions giving rise to these springs (pp. 210–213).

301 —— The basin of eastern Persia and Sistan.

Explorations in Turkestan, with an account of the basin of eastern Persia and Sistan—Carnegie Institution of Washington, pp. 217–317, 25 figs.
Notes the use of springs and subterranean drainage tunnels in the irrigation of eastern Persia (pp. 226, 304, 305). Mentions absorption of water of streams by gravels (pp. 247, 249, 252, 276). Quotes Holdich, who ascribes the waterless conditions of portions of southern Baluchistan to a gradual exhaustion of the subterranean supply (p. 303). Quotes Sykes to show that in the higher mountains of this corner of Persia water can usually be found by digging in the water courses (p. 304). Notes existence of brackish water in wells in the desert at a depth of 5 feet (pp. 304, 305). Legends relating to the drying up of the springs are given (pp. 312–314).

I.

302 **Ingalls** (O. L.). Present and prospective sanitation of Manila.
Trans. Assoc. Civil Eng. of Cornell Univ., pp. 105–112.
Gives the ground-water infiltration into the sewers of Manila as 1,250,000 gallons per square mile per day. Notes that all sewers are laid at a considerable distance below sea level in soil saturated with water.

303 **Irrigation.** Bonita Valley [Colorado].
Irrigation, vol. 2, pp. 3–4, 1 fig.
Notes the existence of numerous wells 10–70 feet deep in the valley furnishing water for domestic use the year round.

304 —— Roswell artesian basin.
Irrigation, vol. 2, no. 5, p. 5.
Describes the location, character of rocks, artesian-water horizons, source of supply, depth of wells, pressure, and decrease in flow of the Roswell artesian basin, in the Pecos Valley, New Mexico.

305 —— [Irrigation by artesian flow].
Irrigation, vol. 2, no. 5, p. 17.
Notes the use of the underflow for irrigation in Colorado.

306 —— Idaho's bounteous water supply.
Irrigation, vol. 3, no. 5, pp. 5–6, 1 fig.
Describes the numerous springs issuing from water-bearing beds outcropping in the Snake River Canyon. Notes the existence of hot, fissure springs on the Snake River plains. Mentions the use of the spring water for irrigation.

307 —— Wyoming farmers are prosperous.
Irrigation, vol. 3, no. 5, pp. 13–14.
Mentions a flowing well 1,000 feet deep near Laramie, Wyo., and notes the existence of many wells in this section, the water of which is used for stock and domestic and irrigation purposes.

308 —— How land is prepared for irrigation and water applied for crops.
Irrigation, vol. 4, no. 2, pp. 3–5, 3 figs.
Notes the use of spring water in irrigation in Scott County, Nebr. (p. 5).

309 **Irrigation Age.** [Artesian water in the Pecos Valley, New Mexico.]
Irrigation Age, vol. 20, p. 88.
Notes the existence of an inexhaustible supply of water underlying the desert land in this vicinity.

310 —— Artesian wells.
Irrigation Age, vol. 20, p. 174.
Describes the obtaining of flowing wells and their use in the irrigation of the Snake River lands, Idaho.

311 —— South Dakota irrigation.
Irrigation Age, vol. 20, p. 216.
Describes results attained by irrigation from an artesian well with a flow of 550 gallons per minute.

312 —— Measuring the flow in underground streams.
Irrigation Age, vol. 20, p. 233, 2 figs.
Describes electrical method of Prof. C. S. Slichter.

313 —— A neglected opportunity in arid reclamation.
Irrigation Age, vol. 21, p. 16.
Describes the disappearance of numerous streams in Idaho in passing over gravel deposits, and states that the diversion of canals from these streams would result in an appreciable saving of water.

314 **Irrigation Age.** Preparing land for irrigation and methods of applying water.
Irrigation Age, vol. 21, pp. 24–26.
Describes the use of springs in irrigation in Scott County, Nebr.

315 —— Lake View ranch [Frio Co., Texas].
Irrigation Aid, vol. 2, no. 4, pp. 10–11, 15.
Describes a well which furnishes water for irrigation, and describes pumping tests made upon it.

316 —— San Marcos [Texas].
Irrigation Aid, vol. 2, no. 6, pp. 2–12, 9 figs.
Contains a description of the flowing well at the United States Fish Culture station at this place.

317 **Irrigation Aid.** Ho Ra Company's pumping plants.
Irrigation Aid, vol. 1, no. 5, p. 16.
Describes one of the wells of this company and the effect of pumping upon the level of the water in the well.

318 —— Irrigating from wells near Cotulla [Texas].
Irrigation Aid, vol. 1, no. 5, p. 23.
Describes a well 225 feet deep, the water of which is used for irrigation.

319 —— Pumping at Centerpoint [Texas].
Irrigation Aid, vol. 1, no. 5, p. 23.
Describes a well 225 feet deep, the water from which is used for irrigation.

320 —— In the Devine country [Texas].
Irrigation Aid, vol. 2, no. 2, pp. 4–7.
Describes several wells in this section, the water of which is used for irrigation.

321 —— Kingsville [Texas].
Irrigation Aid, vol. 2, no. 3, pp. 5–7, 17–19, 1 fig.
Describes several flowing wells in this region.

322 —— Falfurrias [Texas].
Irrigation Aid, vol. 2, no. 4, pp. 4–7.
Describes several flowing wells which furnish water for irrigation.

323 —— Artesia [Texas].
Irrigation Aid, vol. 2, no. 5, pp. 4–6.
Describes several flowing wells which furnish water for irrigation purposes.

324 —— Wells.
Irrigation Aid, vol. 2, no. 5, pp. 21–22.
A brief description of dug, driven, and drilled or bored wells.

325 —— Lake View ranch [Frio Co., Texas].
Irrigation Aid, vol. 2, no. 6, pp. 12–15.
Describes a well which furnishes water for irrigation, and describes pumping tests upon it. Notes that water can be obtained in the vicinity of Dilley at a depth of 40–60 feet.

326 —— Red River project [Oklahoma].
Irrigation Aid, vol. 3, no. 4, pp. 18–19.
Mentions three salt springs which flow into Elm Fork, a branch of the North Fork of Red River.

327 **Irving** (John Duer). Ore deposits of the Ouray district, Colorado.
Bull. U. S. Geol. Survey no. 260, pp. 50–77.
Considers part of ground water in ore deposition (pp. 65, 69–71, 75).

328 **Irving** (John Duer). The ore deposits of the Ouray quadrangle, Colorado.

Abstract: Science, new ser., vol. 21, pp. 916–917.

Gives theory of origin due to ascension of alkaline waters and replacement of quartzite along fissures.

J.

329 **Jackson** (Daniel D.). The normal distribution of chlorine in the natural waters of New York and New England.

Water-Sup. and Irr. Paper no. 144, U. S. Geol. Survey, 31 pp.

Notes the influence of geologic deposits on chlorine in inland States (p. 10), and furnishes chlorine maps and tables showing source of waters examined (lakes, streams, ponds, and wells) for each of the New England States and New York.

330 **Jaggar** (Thomas A., jr.) and **Palache** (Charles). Description of the Bradshaw Mountains quadrangle [Arizona].

Geologic Atlas U. S., folio 126, U. S. Geol. Survey, 11 pp., 4 maps, 1 illus. sheet.

Describes deposits of travertine and onyx breccia formed by hot springs (p. 3). Notes the use of mine water and springs for mine operations (p. 11).

331 **James** (George D.). Notes on Death Valley and the Panamint.

Eng. and Min. Jour., vol. 80, pp. 914–918, 7 figs., 1 map.

Furnishes map showing the location of the springs in this district. Notes the absorption of water by sands and gravels and its subsequent reappearance in wells and springs, and states that the water from the springs is good.

332 **Janin** (George). The Montreal waterworks [Quebec].

Municipal Engineering, vol. 29, pp. 278–280.

Notes the supplying of the city about 1800 by springs from Mount Royal.

332a **Jensen** (Charles A.) and **Mackie** (W. W.). Soil survey of the Baker City area, Oregon.

Field Operations of the Bureau of Soils, 1903, U. S. Dept. Agr., pp. 1151–1170, 1 fig., 4 maps.

Discusses the influence of irrigation in raising the ground-water level and in rendering the soil in many localities highly alkaline. Methods of drainage for alkaline tracts are proposed.

333 —— and **Strahorn** (A. T.). Soil survey of the Bear River area, Utah.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 995–1023, 3 maps, 1 fig.

Discusses the occurrence of underground and seepage waters (pp. 1013-1014), furnishes map showing depths to water table (map 46), and discusses its relations to alkali in the soil (pp. 1014–1018). Mentions occurrence of springs and flowing artesian wells, and notes their usual composition (p. 1018).

334 —— **Lapham** (Macy H.) and. Soil survey of the Bakersfield area, California.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 1089–1114, 3 maps, 1 fig.

See Lapham (Macy H.) and Jensen (Charles A.).

335 **Johnson** (Douglas Wilson). Relation of the law to underground waters.

Water-Sup. and Irr. Paper no. 122, U. S. Geol. Survey, 55 pp.

Discusses the common-law rulings concerning underground waters moving by general percolation or definite channels, and quotes decisions concerning the same; legislative acts passed by the various State legislatures for the purpose of regulating the use or pollution of underground waters are also given.

336 **Johnson** (E., jr.), **Hall** (M. R.), and **Hoyt** (John C.). **Report of progress of stream measurements for the calendar year 1904: Part V, Eastern Mississippi River Drainage.**

Water-Sup. and Irr. Paper no. 128, U. S. Geol. Survey, 168 pp.

See Hall (M. R.), Johnson (E. jr.), and Hoyt (John C.).

337 **Johnson** (L. C.). Mississippi.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 170–178, 1 fig.

Describes water-bearing strata in the Carboniferous, Cretaceous, Tertiary, and Pleistocene formations. Gives a list of mineral springs and of publications relating to underground waters of the State.

338 **Johnson** (R. D. O.). The diamond drill in Missouri.

Eng. and Min. Jour., vol. 80, pp. 243–245.

Describes the encountering of channels, sometimes water bearing, in which the water fed to the bit fails to come to the surface. The methods of getting by these openings are discussed.

339 —— Lead mining in southeastern Missouri.

Eng. and Min. Jour., vol. 80, pp. 481–482.

Contains descriptions of the quantity of water encountered in the shafts of this district.

340 **Jones** (Helen Lukens). The water system of Pasadena.

The official proceedings of the Twelfth National Irrigation Congress at El Paso, Tex., November 15–18, 1904, pp. 137–138.

Discusses the water supply of Pasadena, Cal., derived entirely from pumping wells, and states methods of economy in use of water.

341 **Jones** (Jessie). Corrosion of brass and bronze by mine water.

Metal Industry, vol. 3, pp. 9, 171; Mining Reporter, vol. 52, pp. 623–624; Chemical Engineer, vol. 2, pp. 358–361.

Contains analyses of the water in the mines of the Lehigh and Wilkesbarre Coal Company, near Audenried, Carbon County, Pa., and descriptions of tests made to determine the effect of these waters upon brass and bronze.

342 **Jones** (John T.). Unwatering the Hamilton mine. [Michigan.]

Eng. and Min. Jour., vol. 80, pp. 867–868.

Describes the encountering of a water cavern while drilling in one of the shafts, the immense head on the water, the drainage of water from higher level of a near-by mine, the subsequent filling of both mines by the water, and the steps taken to exhaust the contents of the cavity, after which the flow of water was normal.

343 **Journal of Geography.** The Monarch Geyser. [New Zealand.]

Jour. Geog., vol. 4, p. 143.

Brief description of the geyser Waimangu, near Roturua, New Zealand. This geyser made its appearance two years ago and is about half an acre in extent.

K.

344 **Kansas,** State Board of Health of.

Second Biennial Report or the Nineteenth and Twentieth Annual reports, from January 1, 1903, to December 31, 1904, 182 pp.

Discusses the contamination of well water at Holton by sewage (pp. 70–71).

345 **Kearney** (Thomas H.). Agriculture without irrigation in the Sahara Desert.

Bull. Bureau of Plant Industry, U. S. Dept. Agr., no. 86, 27 pp., 5 pls., 1 fig., 1 map.

Notes the occurrence of thousands of shallow wells in the Souf country. Describes method of raising water by means of bucket and pole; mentions occurrence of magnesium water in some regions, and gives analysis (pp. 16–17).

346 **Kearney** (Thomas H.) and **Means** (Thomas H.). Agricultural explorations in Algeria.

Bull. Bureau of Plant Industry, U. S. Dept. Agr., no. 80, 98 pp., 4 pls.

Refers to unsuccessful attempts to find artesian water in the High Plateau region (p. 16). Mentions large subterranean streams in the sands of the Sahara region and their utilization in the creation of oases (pp. 18, 36). Describes the original method of sinking wells in the Oved Rirh region of the Sahara by means of wooden casing, and danger to diggers owing to sudden rise of water (pp. 36–37). Gives history of artesian boring in the Oved Rirh region and great value of the flowing wells (p. 37). Gives composition of the water (pp. 37–38) and states injury to soil by deposition of soluble salts in it.

347 **Keith** (Arthur). Description of the Mount Mitchell quadrangle [North Carolina-Tennessee].

Geologic Atlas U. S., folio 124, U. S. Geol. Survey, 9 pp., 4 maps, 1 col. sect. sheet.

Mentions deposition of pegmatite from mineralized waters (p. 3), decomposition of rock by waters circulating along schistose planes (p. 3), and alteration of dunite to serpentine by infiltrating waters (p. 4). Refers to the abundance of springs (p. 9).

348 —— Economic geology of the Bingham mining district, Utah. Part 1, Areal geology.

Prof. Paper U. S. Geol. Survey no. 38, pp. 27–70.

Describes alteration of limestone through action of underground waters circulating along fissures (pp. 66–69).

349 **Keith** (N. S.). New methods in the metallurgical treatment of copper ores.

Jour. Franklin Institute, vol. 160, pp. 147–155.

Notes the existence of cupriferous sandstones in New Brunswick, Connecticut, New York, New Jersey, and Pennsylvania, the quartz grains of which are cemented together by silica from thermal waters carrying silica in solution. The silica in solution is suggested as due to the solvent action of the thermal waters on the sand itself while lying on a horizontal plane.

350 **Kellerman** (Karl F.), **Moore** (George T.) and. Copper as an algicide and disinfectant in water supplies.

Bull. Bureau of Plant Industry, U. S. Dept. Agr., no. 76, 55 pp.

See Moore (George T.) and Kellerman (Karl F.).

351 **Kemp** (James Furman). The copper deposits at San Jose, Tamaulipas, Mexico.

Bimonthly Bull., Am. Inst. Min. Eng., no. 4, pp. 885–910, 3 figs.

In discussing the genesis of these deposits the writer considers the part played in their formation by underground waters.

352 —— Secondary enrichment in ore deposits of copper.

Econ. Geol., vol. 1, pp. 11–33.

Contains a number of references to the part played by ascending magmatic waters and by descending meteoric waters in the deposition or enrichment of copper ores.

353 **Kerr** (Mark B.). Formation of ore bodies on intersections.

Min. and Sci. Press, vol. 90, pp. 253–254, 4 figs., and vol. 90, p. 241.

Describes the agency of underground waters in the formation of the deposits.

354 **Keyes** (Charles Rollin). Geology and underground-water conditions of the Joranda del Muerto, New Mexico.

Water-Sup. and Irr. Paper no. 123, U. S. Geol. Survey, 42 pp.

Describes geologic conditions in detail and discusses the occurrence of underground waters, which are obtained from the base of the Red Beds, from the Cretaceous sandstones, and from the surface gravels. Analyses of the water are given (p. 36), the wells described (p. 37), the artesian prospects discussed (p. 38), and the possibility of irrigation from well waters considered (p. 39).

355 **Kindle** (Edward M.). Salt and other resources of the Watkins Glen district, New York.

Bull. U. S. Geol. Survey no. 260, pp. 567–572.

Gives two well records (pp. 568–569).

356 —— Water resources of the Catatonk area, New York.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 53–57.

Discusses the underground-water conditions in the drift and Devonian shales, and describes the artesian wells at Ithaca and Slaterville and the sulphur and other mineral springs at a considerable number of localities. The water is supposed to come from the Genesee formation, the sulphur probably coming from decomposing pyrite.

357 **King** (Charles R.). The Simplon tunnel.

Eng. and Min. Jour., vol. 79, p. 856.

Contains descriptions of the underground waters encountered in the construction of the tunnel between Switzerland and Italy.

358 —— The completion of the Simplon tunnel. [Between Switzerland and Italy.]

Sci. Am., vol. 92, p. 226, 8 figs.

This article is devoted almost entirely to a description of the springs encountered. Photographs of several are given.

359 —— The completion of the Simplon tunnel.

Sci. Am. Supp., vol. 59, pp. 24430–24432, 16 figs; also on pp. 24452–24455, 9 figs.

A very complete description of the hot springs encountered, their temperature, volume, pressure, location, etc., forms the greater part of these articles.

360 **King** (F. H.). Some results of investigations in soil management.

Yearbook U. S. Dept. Agr., 1903, pp. 159–174.

Discusses porosity and capillarity of soils, effect of plowing, loss of water by evaporation, etc.

361 **Kingsville Spokesman.** Artesian belt [Texas].

Irrigation Aid, vol. 3, no. 1, p. 18.

Describes the underground-water conditions of southwestern Texas.

362 **Kinney** (Bryce A.). Annual report of the State natural-gas supervisor.

Twenty-ninth Ann. Rept. Indiana Dept. Geol. and Nat. Res., pp. 757–770.

Gives several brief records of gas wells (pp. 764–766).

363 **Knapp** (George N.). New Jersey.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 93–103, 1 pl.

Describes underground-water conditions in the Appalachian province, crystalline highlands province, Piedmont province, and Coastal Plain province. Gives geologic sections of water-bearing strata (pl. VI). Summarizes well statistics in the Coastal Plain (pp. 98–101); summarizes water resources, distribution of wells, and enumerates mineral springs (p. 102), and lists the principal publications (p. 103).

364 **Knapp** (I. N.). Drilling wells in soft and unconsolidated formations.

Stevens Institute Indicator, January, 1905, 20 pp., 11 figs.

Notes the existence in southern California of vast porous reservoirs of sand, gravel, etc., holding immense quantities of underground water. In the development of these immense supplies the "stovepipe" method described in this paper was developed.

365 **Knight** (Nicholas). Notes on the softening of Iowa well waters.

Chemical Engineer, vol. 2, pp. 89–95, 1 fig.

Describes investigations of the softening of hard water from a well in the Niagara magnesian limestone at Mount Vernon, Iowa. Several analyses are given.

366 **Kraus** (Edward H.). On the origin of the caves of the island of Put-in-Bay, Lake Erie.
Am. Geologist, vol. 35, pp. 167–171.
Notes part played by solution of gypsum in the formation of the caves (pp. 170–171).

367 —— Occurrence and distribution of celestite-bearing rocks.
Am. Jour. Sci., 4th ser., vol. 19, pp. 286–293, 5 figs.
Gives a description of the "Crystal" or "Strontium" cave on the island of Put-in-Bay, Lake Erie. Notes the porous nature of the celestite-bearing rocks of New York and Michigan, and discusses the agency of percolating saline waters in the solution of the celestite. Large, well-developed crystals of celestite occur in cracks and cavities due to deposition from celestite-bearing solutions.

368 **Kümmel** (Henry B.). A report upon some molding sands of New Jersey.
Ann. Rept. New Jersey Geol. Survey for 1904, pp. 187–246, 1 fig.
Discusses factors determining porosity and permeability of sands (pp. 199–204).

369 —— Additional well records.
Ann. Rept. New Jersey Geol. Survey for 1904, pp. 263–271.
Gives descriptions, records, class, and yield of about 30 wells.

L.

370 **Ladd** (E. F.). Water for domestic purposes in North Dakota.
Bull. North Dakota Govt. Agr. Exp. Sta. no. 66, pp. 557–571.
Mentions requirements of safe well water as regards composition, and gives many analyses from various kinds of wells.

371 **La Forge** (Laurence). Water resources of central and southwestern highlands of New Jersey.
Water-Sup. and Irr. Paper no 110, U. S. Geol. Survey, pp. 141–155.
Describes the Schooley Mountain mineral spring and gives analysis (p. 148). Enumerates towns having springs and wells as public supply and mentions good quality of the water (p. 151).

372 **Laird** (George A.). The gold mines of the San Pedro district, Cerro de San Pedro, State of San Luis Potosi, Mexico.
Bimonthly Bull. Am. Inst. Min. Eng., no. 1, January, 1905, pp. 69–89, 5 tables, 1 map.
Concludes that the deposits were originally formed and the upper portions subsequently enriched by the action of underground water.

373 **Lakes** (Arthur). Organic remains in ore deposits.
Eng. and Min. Jour., vol. 79, pp. 1226–1227.
Discusses the agency of mineral-bearing solutions in the preservation of organic remains and the influence of organic remains in the precipitation of minerals from solutions.

374 —— Igneous rocks in ore deposition.
Eng. and Min. Jour., vol. 80, p. 196.
Contains a discussion of the agency of igneous rocks in the formation of openings along which ore-bearing solutions could pass.

375 —— Oil-impregnated volcanic dikes in Colorado.
Mines and Minerals, vol. 25, p. 394, 3 figs.
Notes the occurrence of springs of water issuing at the sides of the dikes.

376 —— Sketch of the economic resources of the foothills of the Front Range of Colorado.
Min. Reporter, vol. 51, pp. 522–524, 1 fig.
Contains a brief statement of the artesian-water resources of the area.

377 **Lakes** (Arthur). The hot and mineral springs of Routt County and Middle Park, Colorado.

Min. Reporter, vol. 52, pp. 438–439, 2 figs.

The springs issue from between the Dakota sandstone and Colorado shales. Descriptions are given for several groups of springs.

378 **Lamb** (Richard). Discussion of paper entitled "The reclamation of river deltas and salt marshes."

Proc. Am. Soc. Civil Eng., vol. 31, pp. 204–207.

Quotes Lyell as to existence of vast springs in the Dismal Swamp, and describes the drainage of the swamp by digging wells through clays forming the bed of the swamp into the quicksands beneath.

379 **Landes** (Henry). Preliminary report on the underground waters of Washington.

Water-Sup. and Irr. Paper no. 111, U. S. Geol. Survey, 85 pp. 1 map.

Describes the wells, springs, and geologic occurrence of the waters by counties, the use of spring and well water for municipal and private supply, health resorts, and irrigation. Gives a number of analyses, and discusses the compositions. Gives 16 pages of tables relative to representative wells, springs, and municipal supplies.

380 **Lane** (Alfred C.). Transmission of heat into the earth.

Ann. Rept. Michigan Geol. Survey for 1903, pp. 195–237, 6 figs.

Mentions method of deriving depth of well from temperature of its water (p. 195).

381 —— Deep borings for oil and gas.

Ann. Rept. Michigan Geol. Survey for 1903, pp. 273–294, 1 fig.

Gives a number of records, discusses the divining-rod delusion as applied to water (pp. 276–279), and mentions occurrences of salt water.

382 —— Sixth annual report of the State geologist to the board of the Geological Survey for the year 1904.

Ann. Rept. Michigan Geol. Survey for 1904, pp. 113–168, 1 pl.

Describes the occurrence of salt water in an oil well near Allegan, Mich. (pp. 164–165).

383 **Lapham** (Macy H.). Soil survey of the San Jose area, California.

Field Operations of the Bureau of Soils, 1903, U. S. Dept. Agr., pp. 1183–1217, 1 fig., 1 map.

Defines artesian water, water table, etc.; describes irrigation by flowing and nonflowing artesian wells; mentions artesian strata; describes pumping plants, relation of capillarity to rock texture, and relation of seepage to height of water table and occurrence of alkali (pp. 1204–1211).

384 —— and **Jensen** (Charles A.). Soil survey of the Bakersfield area, California.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 1089–1114, 3 maps, 1 fig.

Describes occurrences of underground and seepage waters, and relation to alkali in the soil (pp. 1107–1108). Discusses briefly the distribution of artesian wells, pumping plants, and use of the water for domestic purposes (pp. 1106–1107).

385 —— and **Neill** (N. P.). Soil survey of the Solomonsville area, Arizona.

Field Operations of the Bureau of Soils, 1903, U. S. Dept. Agr., pp. 1045–1070, 1 fig., 1 map.

Mentions average depth of wells and of water table; describes injurious effects of alkali in waters, inferiority of deep-well water, gives analysis, and injurious effect of seepage (pp. 1062–1064).

386 **Lapham** (Macy H.), **Root** (Aldert S.), and **Mackie** (W. W.). Soil survey of the Sacramento area, California.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 1049–1087, 1 map, 1 fig.

Describes irrigation from pumped wells in portions of the area (p. 1081).

387 **Lee** (Willis Thomas). Underground waters of Salt River Valley, Arizona.

Water-Sup. and Irr. Paper no. 136, U. S. Geol. Survey, 196 pp.

This paper starts with descriptions of deep and seepage wells, including volume, cost, interference, materials penetrated, pumping tests, use for irrigation, and analyses of the waters, and gives tables showing location, character, depth, diameter, head, volume, permanency, etc., of wells. These are followed by chapters on geology and physiography, after which the economics of the supplies are considered. The character of the water table is shown by a contour map. The fluctuations of the latter and the underflow of Salt River and the valley in general are discussed in detail. Much of the water is in bowlder beds representing buried stream channels. Other features discussed are the chemistry of the waters, the occurrence, origin, and effect of salt on vegetation, the measurement of underflow by the Slichter underflow meter, the available water, and the cost of pumping. The discussion of the origin of caliche, a calcareous crust formed in the sediments some distance below the surface, is of much interest.

388 **Leffmann** (Henry). The microscopic structure of building stones.

Proc. Eng. Club of Philadelphia, vol. 22, pp. 327–346, 12 figs.

Describes the cementation of sediments by infiltrating solutions (p. 337).

389 **Leighton** (Marshal Ora). Sanitary regulations governing construction camps.

Water-Sup. and Irr. Paper no 146, U. S. Geol. Survey, pp. 90–93.

Points out precautions to be taken in use of wells (p. 93).

390 —— Field assay of water.

Water-Sup. and Irr. Paper no. 151, U. S. Geol. Survey, 77 pp.

Describes a field outfit for the rapid analysis of surface and underground waters in the field.

391 **Leith** (Charles Kenneth). A summary of Lake Superior geology with special reference to recent studies of the iron-bearing series.

Bimonthly Bull. Am. Inst Min. Eng., no. 3, 1905, pp. 453–507, 1 map, 2 tables, 4 figs.

Contains a discussion of the agency of underground waters in the formation of iron-ore deposits.

392 —— Genesis of Lake Superior iron ores.

Econ. Geol., vol. 1, pp. 47–66.

This paper presents an important summary of the occurrence of water in fractured and brecciated rocks. The topics discussed include the convergence of waters through joints, fractures, brecciated zones, bedding planes, and structural troughs (pp. 55, 61). The irregular nature of the trunk channels of the underground waters (p. 56), the relation of circulation to impervious beds, and the resulting ponding and flow (p. 57), the lower limit of waters affecting ore deposition (p. 59), the relation of ore concentration to circulation of waters (p. 59), and the nature of mine waters (p. 62) are also considered.

393 **Leopold** (F. B.). Filtration of water in its relation to the health and prosperity of a municipality.

Proc. Am. Waterworks Assoc., pp. 276–296, 4 figs.

Describes epidemic caused by use of polluted well waters at Ithaca and Elmira, N. Y. A short description of the well-supply system of Columbus, Ohio, is quoted from the Engineering News of February 11, 1904. Notes epidemic at Mount Savage, Va., caused by polluted spring waters. An instance of the pollution of well waters in cities is also given.

394 **Leverett** (Frank). Illinois.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 248–257, 2 pls., 1 fig.

Describes the various water-bearing formations and their relations to artesian and other wells, and discusses their quality and use. Lists the important mineral springs and principal publications regarding underground waters of the State.

395 —— Indiana.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 258–264, 2 pls.

Describes the principal water-bearing formations and discusses favorable localities for wells, giving map. Describes general distribution of spring water and gives list of principal commercial springs. Lists the principal publications pertaining to underground waters of the State.

396 —— Ohio.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 265–270.

Describes the various water-bearing formations and discusses localities favorable for artesian wells. Lists the principal mineral springs and the publications relating to underground waters of the State.

396a **Levy** (E. C.), **Whipple** (George C.) and. The Kennebec Valley typhoid-fever epidemic of 1902–1903. [Maine.]

Jour. New England Waterworks Assoc., vol. 19, pp. 163–214, 7 figs.

See Whipple (George C.) and Levy (E. C.).

397 **Lewis** (Joseph Volney), **Pratt** (Joseph Hyde) and. Corundum and the peridotites of western North Carolina.

North Carolina Geol. Survey, vol. 1, 464 pp., 45 pls., 35 figs.

See Pratt (Joseph Hyde) and Lewis (Joseph Volney).

398 **Lewis** (L. L.) and **Nicholson** (J. F.). A study of a few representative sources of drinking water.

Bull. Oklahoma Agr. Exp. Sta. no. 66, pp. 12–19.

A brief bacteriological study of water from 14 wells at Stillwater, Okla., giving source of water and number of bacteria. Mentions dangers of contamination.

399 **Lindgren** (Waldemar). The occurrence of stibnite at Steamboat Springs, Nevada.

Bimonthly Bull. Am. Inst. Min. Eng. no. 2, 1905, pp. 275–278.

Describes these hot springs; gives analyses of the water and sinter deposited from one of the springs; describes the sinking of a shaft on the sinter flats a few hundred feet away and the encountering of hot water in a gravel bed and the discovery of stibnite crystals in the gravel.

400 —— Ore deposition and deep mining.

Econ. Geol., vol. 1, pp. 34–46.

Discusses the part played by water in ore deposition (p. 43), the enrichment of ores by descending waters (pp. 35, 37), and considers the conditions of precipitation (pp. 40, 44).

401 —— Chemistry of copper deposits.

Eng. and Min. Jour., vol. 79, p. 189.

This article is a letter to the editor in reply to a criticism by a correspondent of Mr. Lindgren's views on the chemistry of copper and sulphur as expressed in an article on the Clifton deposits in Arizona, which had previously appeared in the journal. The agency of underground waters in the formation of the copper deposits at Clifton is discussed.

402 —— Characteristics of gold-quartz veins in Victoria [Australia].

Eng. and Min. Jour., vol. 79, pp. 458–460, 1 fig.

Discusses the agency of mineralized waters in the formation of these veins.

403 **Lindgren** (Waldemar). Description of the Clifton quadrangle [Arizona].

Geologic Atlas U. S., folio 129, U. S. Geol. Survey, 13 pp., 4 maps, 3 figs., 1 col. sect.

Refers to the great volume of water mingled with Tertiary volcanic eruptions (p. 8). Mentions alteration of ore deposits in limestone by oxidizing waters (pp. 12, 13). Describes formation of quartz veins by aqueous solutions, and reviews theories (p. 13). Notes scarcity and great depth of ground water (p. 12). Describes the distribution of springs, including thermal and mineral springs, and gives analysis (p. 13).

404 —— and **Ransome** (F. L.). The geological resurvey of the Cripple Creek district, Colorado.

Bull. U. S. Geol. Survey no. 260, pp. 85-98.

Describes occurrence of water in fractured area surrounded by impervious rocks, the fractures holding the water as in a reservoir (pp. 96-97). Also notes the depth of oxidization (p. 94) and the occurrence of carbon dioxide, nitrogen, and oxygen, which are considered as exhalations from an igneous mass below.

405 —— The copper deposits of the Clifton-Morenci district, Arizona.

Prof. Paper U. S. Geol. Survey no. 43, 375 pp., 25 pls., 19 figs.

Describes the ground-water conditions in mines, noting the general absence of water (pp. 22, 212, 226, 232, 318, 333) and the occurrence of springs (p. 317). The part of water in ore deposition and metasomatic processes, including both common hydrometamorphism by circulating meteoric waters, hydrothermal metamorphism, and oxidation, are considered in great detail, and the chemical reactions discussed (pp. 123–194, 331 et seq.). The work of magmatic waters (p. 219) and the alteration by oxidizing waters are also treated at length (pp. 20–24, 197, 213, 333).

406 —— Mining the Australian deep leads.

Min. Magazine, vol. 11, pp. 139–143, 4 figs.

Describes the occurrence of water in the buried gravels; notes that long-continued pumping causes a funnel-shaped depression in the ground-water table.

407 **Lines** (Edwin F.). Well records.

Bull. U. S. Geol. Survey no. 264, pp. 41–106.

Gives summary records of over 350 oil, gas, and water wells, and detailed logs for a considerable number.

408 **Lippincott** (J. B.). Water problems of Santa Barbara, Cal.

Water-Sup. and Irr. Paper no. 116, U. S. Geol. Survey, 99 pp.

Notes discharge, etc., of deep city wells (pp. 11, 33) and describes collecting tunnel over 5,000 feet long, in which flow is regulated by bulkheads (p. 33). Figures of discharge (p. 33) and an analysis of the tunnel water (p. 37) are given. To secure further supply it is intended to continue tunnel through the mountain to a stream on the other side.

409 **Little** (Etta). Sanitary analysis of the water of Fulbright Spring.

Bull. Bradley Geol. Field Sta. of Drury College, vol. 1, pt. 2, pp. 50–52.

Gives a new analysis of the water of one of the springs furnishing the public supply at Springfield, Mo., and a number of older ones of the supplies of other Missouri cities.

410 **Livingston** (Burton Edward). The relation of soils to natural vegetation in Roscommon and Crawford counties, Mich.

Ann. Rept. Michigan Geol. Survey for 1903, pp. 9–32, 1 pl.

Discusses relation of ground-water level to type of vegetation (pp. 23-24).

411 **Logan** (W. N.) and **Perkins** (W. R.). The underground waters of Mississippi.

Bull. Mississippi Agr. Exp. Sta. no. 89, 112 pp., 23 figs.

Designates various water-bearing horizons (p. 10), classifies underground waters by locality and composition (pp. 10–12), enumerates factors affect-

ing purity (pp. 12–13), describes artesian water in general (p. 6), and discusses Mississippi artesian- and deep-well waters in detail by counties and towns (pp. 14–112), giving geological relations, well sections, and analyses; states whether flowing or nonflowing, potability, etc.

412 **Loveland** (G. A.). Increased flow of spring water in the autumn.

Monthly Weather Review, vol. 32, pp. 176–177.

Attributes increased flow in Nebraska in October and November to the slow percolation of the water from the heavy rainfall of May, June, and July, combined with the decreased evaporation due to lower temperature and the smaller demands of vegetation.

413 **Lyman** (Kate). Chemical analysis of the water of Fulbright Spring.

Bull. Bradley Geol. Field Sta. of Drury Coll., vol. 1, pt. 2, pp. 49–50.

An analysis of one of the springs furnishing the public supply at Springfield, Mo.

414 —— **Park** (Emma J.) and. The Springfield water supply: Description of springs and the geology of the district.

Bull. Bradley Geol. Field Sta. of Drury Coll., vol. 1, pt. 2, pp. 45–49.

See Park (Emma J.) and Lyman (Kate).

415 —— **Park** (Emma J.) and. The Hannibal formation in Greene County [Missouri].

Bull. Bradley Geol. Field Sta. of Drury Coll., vol. 1, pt. 2, pp. 79–90.

See Park (Emma J.) and Lyman (Kate).

416 **Lyman** (W. S.), **Caine** (Thomas A.) and. Soil survey of the San Antonio area, Texas.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 447–473, 1 map, 1 fig.

See Caine (Thomas A.) and Lyman (W. S.).

M.

417 **Macbride** (Thomas H.). Geology of Emmet, Palo Alto, and Pocahontas counties [Iowa].

Ann. Rept. Iowa Geol. Survey, 1904, vol. 15, pp. 229–259, 1 pl. 3 figs., 3 maps.

Gives well records (pp. 252, 254) and mentions shallow and deep wells and springs as sources of country and city supply (p. 259).

417a **McCalley** (Henry), **Smith** (Eugene Allen) and. Index to the mineral resources of Alabama.

Alabama Geol. Survey, 1904, 79 pp., map and 6 pls.

See Smith (Eugene Allen) and McCalley (Henry).

418 **Mackie** (W. W.), **Jensen** (Charles A.), and. Soil survey of the Baker City area, Oregon.

Field Operations of the Bureau of Soils, 1903, U. S. Dept. Agr., pp. 1151–1170, 1 fig., 4 maps.

See Jensen (Charles A.) and Mackie (W. W.).

419 —— **Root** (Aldert S.), **Lapham** (Macy H.) and. Soil survey of the Sacramento area, California.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 1049–1087, 1 map, 1 fig.

See Lapham (Macy H.), Root (Aldert S.), and Mackie (W. W.).

420 **Maguire** (Don). Oil and asphaltum on the shores of Great Salt Lake, Utah.

Min. and Sci. Press, vol. 90, p. 302, 2 figs.

Describes the saline and oil springs and notes the encountering of salt water carrying much sulphuric acid in a 2,700-foot boring.

421 **Mangum** (A. W.) and **Drake** (J. A.). Soil survey of the Russell area, Kansas.

Field Operations of the Bureau of Soils, 1903, U. S. Dept. Agr., pp. 911–926, 1 fig., 1 map.

Mentions the occurrence of springs along the outcrop of the base of the Dakota sandstone (p. 914).

422 **Mark** (Edward L.). The Bermuda Islands and the Bermuda Biological Station for Research.

Pop. Sci. Monthly, vol. 66, pp. 393–411, 12 figs.

Describes the caves, sinks, and subterranean passages in the limestone of the island.

423 **Marriott** (Hugh F.). Electrical devices for deep borehole surveying.

Eng. News, vol. 54, pp. 91–94.

Describes in detail the instruments and methods of use with numerous diagrams. Editorial review on p. 97.

424 **Martin** (George C.). The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits.

Bull. U. S. Geol. Survey no. 250, 64 pp. 7 pls., 3 figs.

Notes the occurrence of oil and gas springs and seeps (pp. 22, 27, 47, 55, 58), gives well records (pp. 23, 49, 55), mentions the occurrence of water in oil wells (pp. 24, 49, 55), describes blows of water and gas (p. 49), and the association of water with faulting (p. 55).

425 —— Notes on the petroleum fields of Alaska.

Bull. U. S. Geol. Survey no. 259, pp. 128–139.

Gives a number of well records (pp. 131, 133), notes difficulties due to water in oil wells (pp. 132, 133, 136), and describes water and oil seepages (pp. 132, 135, 138, 139), and gas and water blows (p. 134).

426 —— Water resources of the Accident and Grantsville quadrangles, Maryland.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 168–170.

Refers to the abundance of good springs, especially in the Greenbrier limestone, and notes the Deer Park spring as an example. States the probabilities of obtaining good artesian water in the region.

427 —— Water resources of the Frostburg and Flintstone quadrangles, Maryland and West Virginia.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 171–173.

Notes the abundance of good springs in the Greenbrier and Helderburg limestones and their use for town supplies. Notes one artesian well obtaining water in Carboniferous sandstones, and states the probability of getting water in the Oriskany and Tuscarora sandstones.

428 —— **Stose** (George W.) and. Water resources of the Pawpaw and Hancock quadrangles, West Virginia, Maryland, and Pennsylvania.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 58–63.

See Stose (George W.) and Martin (George C.).

429 **Martin** (J. O.) and **Sweet** (A. T.). Soil survey of the Kearney area, Nebraska.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 859–874, 1 pl., 1 map, 1 fig.

Describes briefly the occurrence of underground and seepage waters, and their relation to irrigation (p. 870).

430 **Mason** (Russell T.). Peru.

Eng. and Min. Jour., vol. 79, pp. 1091–1093, 1 fig.

Mentions the existence of hot springs depositing sinter at Huancavelica, Peru.

431 **Mason** (William P.). Sundry notes on deep-seated waters.

Proc. Am. Waterworks Assoc., 1905, pp. 297–301, 8 figs.

This article is an abstract of a paper read before the association by W. P. Mason. The terms ground water and deep-seated water are defined; two diagrams given show the conditions governing a flowing and a dry artesian well; the depletion of the deep water in the vicinity of London, England, due to excessive use is noted; the pressure, depth, etc., of the Woonsocket, S. Dak., artesian well, is given; relation between the Jacksonville artesian well and a sea spring off the east coast of Florida is noted; the spring-water supply of Orleans, France, and the deep-well supply of Copenhagen are mentioned; contamination of deep water is touched upon and examples noted; the term "contributing watershed" is defined and an ideal section given; a short discussion of the Sea Mills of Cephalonia concludes the article.

432 —— The water supply of Amsterdam, Holland.

Eng. News, vol. 53, pp. 437–438, 4 figs.

Describes the supplies obtained from the "sand dunes."

433 —— The Sea Mills of Cephalonia.

Eng. News, vol. 54, p. 352, 1 illustration.

Describes the mills at Cephalonia, the largest of the Ionian Islands; notes tests made to determine the course of the water. Suggests that the water "which sinks into the rocks at Cephalonia comes to the surface again in the form of steam at Stromboli, Vesuvius," etc. W. O. Crosby's explanation of the phenomenon is given. A view of the mill is given.

434 —— Relation of intensity of typhoid fever to character of water carriage.

Jour. New England Waterworks Assoc., vol. 19, pp. 412–421.

Describes typhoid epidemics caused by using polluted well water at Waterville, Me., and Philadelphia, Pa. In the discussion accompanying the article Dr. G. A. Soper described the epidemic due to the use of a polluted well water at Ithaca, N. Y.; Messrs. M. N. Baker and G. W. Wright described epidemics due to the use of polluted well waters.

435 —— Interpretation of a water examination.

Science, new ser., vol. 21, pp. 648–653.

States instances of serious pollution in wells and springs, and the difficulties of determining such pollution by analyses (pp. 650–652).

436 **Maury** (Dabney H.). The new well and hydraulic pumping plant at Peoria, Ill.

Eng. Rec., vol. 51, pp. 139–140, 3 figs.

Complete description of the location, sinking of the well, and the equipment of the plant is given.

437 —— New well and hydraulic pumping plant at Peoria, Ill.

Twentieth Ann. Rept. Illinois Soc. Eng. and Surv., pp. 110–118, 4 figs.

Gives references to descriptions of the old wells. Notes exploration of all available water-bearing gravels in the vicinity by test wells; gives the location, elevation at, method of sinking, and capacity of the new well; discusses tests made to show absence of river infiltration; notes flow of water from gravel beds to river, influence of stage of water in river on supply in gravel, and describes the influence of pumping on the underground supply.

438 ——**Burdick** (C. B.), and **Henderson** (C. R.). Report of the committee on waterworks.

Twentieth Ann. Rept. Illinois Soc. Eng. and Surv., pp. 132–139.

Notes the existence of 153 waterwork plants in Illinois deriving their supplies from underground sources (p. 133); mentions the installation of a plant at Freeport for the purpose of removing dissolved iron from deep well water (p. 135). In the discussion of this paper C. A. Prout states that Elgin derives its water from 4 wells, one of which is 2,000 and the others 1,300 feet deep (p. 139).

439 **McCallie** (S. W.). A preliminary report on the coal deposits of Georgia.

Bull. Georgia Geol. Survey no. 12, 121 pp., 14 pls., 60 figs.

Refers to chalybeate springs (pp. 48, 58), and mentions springs from subterranean caverns near Lookout Mountain (p. 18); mentions flooded mines (pp. 56, 68, 75, 81), and describes the interference of undulations in coal seams with the draining of mines (pp. 30, 36); mentions bore holes (p. 41), gives records (pp. 82, figs. 48–53b), discusses them (pp. 102, 104), and discusses briefly the value of records (pp. 102).

440 —— Experiment relating to problems of well contamination at Quitman, Ga.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 45–54, 1 fig.

Describes an attempt to dispose of a city's sewage by forcing it down a deep well into a cavernous limestone. To test the question of pollution a quantity of salt was put into a well and samples of all other wells and springs in the vicinity were taken and analyzed. The results showed that the salt reached the other wells.

441 —— Georgia.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 153–158, 1 fig.

Describes the underground water conditions in the Appalachian Mountain area, the Piedmont Plateau area, and the Coastal Plain area. Lists the principal mineral springs and the important publications regarding underground waters of the State.

442 **McCarthy** (Gerald). Report of Biologist.

Tenth Rept. North Carolina Board of Health, pp. 31–34.

States that 5 water companies in the State obtain their supply from deep wells, and urges the general abandonment of shallow wells for deep wells.

443 **Meachem** (F. G.). Underground temperatures.

Eng. and Min. Jour., vol. 79, p. 368.

Notes the influence of hot and cold springs and the heat produced by the alteration of rocks by percolating water on underground temperatures. Abstract of a paper read before South Staffordshire and East Worcestershire Institution of Mining Engineers.

444 **Mead** (Elwood). Irrigation in northern Italy, Part I.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 144, 100 pp., 17 pls., 14 figs.

Describes use and superiority of springs for marcite irrigation in Lombardy (pp. 9, 60, 64–66); and describes, cause and effect of seepage from canals (pp. 48–53, 79).

445 —— Water rights on interstate streams: The Platte River and tributaries. Water rights within the States.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 157, pp. 96–116.

Discusses return seepage as an obstacle in justly dividing a stream between appropriators in Colorado and Nebraska (pp. 107–108).

446 —— The irrigation investigations in California of the Office of Experiment Stations.

Forestry and Irrigation, vol. 11, pp. 367–369.

Describes the use of underground water in irrigation in this section, the underground-water conditions, the lowering of the water table due partly to a succession of dry seasons, etc.

447 **Means** (Thomas H.). Alkali soils.

Water-Sup. and Irr. Paper no. 146, U. S. Geol. Survey, pp. 108–113.

Describes the movements of alkali in ground water through soil (pp. 111–112).

448 —— **Kearney** (Thomas H.) and. Agricultural explorations in Algeria.

Bull. Bureau of Plant Industry, U. S. Dept. Agr., no. 80, 98 pp., 4 pls.

See Kearney (Thomas H.) and Means (Thomas H.).

449 **Meeker** (F. N.), **Smith** (William G.) and. Soil survey of Sumter County, Alabama.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 317–342, 1 map, 1 fig.

See Smith (William G.) and Meeker (F. N.).

450 **Melluish** (J. G.). Drainage in western Iowa.

Twentieth Ann. Rept. Illinois Soc. Eng. and Surv., pp. 57–65, 2 ill.

Describes the reclaiming of wet lands by means of underground drainage obtained by sinking holes through the swamp bottom into a pervious bed (p. 61). Gives effective diameter of soil grains and rate of flow through soil in several counties (pp. 64–65).

451 **Mendenhall** (Walter C.). Studies of California ground waters.

Forestry and Irrigation, vol. 11, pp. 382–384.

A discussion of the underground-water conditions and resources of southern California. An artesian area in the Colorado Desert is described.

452 —— Development of underground waters in the eastern Coastal Plain region of southern California.

Water-Sup. and Irr. Paper no. 137, U. S. Geol. Survey, 140 pp.

Describes the general ground-water conditions, the source and sufficiency of supply, and the interference and cost of wells. Tables are given showing the owner, location, date of drilling, type, elevation of surface and water, depth, solids in solution, temperature, methods of lift, cost, and use of wells. The maps show distribution of wells, original and present areas of flows, depth to water, and location of pumping plants.

453 —— Development of underground waters in the central Coastal Plain region of southern California.

Water-Sup. and Irr. Paper no. 138, U. S. Geol. Survey, 162 pp.

Treats same topics as no. 452.

454 —— Development of underground waters in the western Coastal Plain region of southern California.

Water-Sup. and Irr. Paper no. 139, U. S. Geol. Survey, 105 pp.

Treats same topics as no. 452.

455 —— The hydrology of San Bernardino Valley, California.

Water-Sup. and Irr. Paper no. 142, U. S. Geol. Survey, 124 pp.

Discusses the development of irrigation, rainfall, effect of forests on water supplies, nature of the return waters, conditions governing the absorption of streams, and the composition (with analyses), flow, temperature, and decline of underground waters. The basin, which is about 8,000 feet deep, is filled with alluvial deposits in which there are many water horizons. Some stratigraphic records and tables, giving the owner, location, depth, composition, temperature, cost, use, etc., of wells, are included. Maps showing wells, artesian areas, etc., are also given.

456 —— Underground waters of southern California.

Water-Sup. and Irr. Paper no. 146, U. S. Geol. Survey, pp. 113–121.

Describes the development of artesian wells for use in irrigation (pp. 114–116), origin of the ground water and its mode of occurrence (pp. 116–117), distribution and character of the supply (pp. 117–118), and the reduction and fluctuation of supply and their causes (pp. 120–121). Desirable precautions in use of water are also pointed out (p. 120).

457 —— The underground waters of southern California.

The official proceedings of the Twelfth National Irrigation Congress at El Paso, Tex., November 15–18, 1904, pp. 150–158.

Describes the artesian areas, their geologic relations, great value, shrinkage in area, problems, etc.

458 **Mesmer** (Louis). Soil survey of the Los Angeles area, California.
Field Operations of the Bureau of Soils, 1903, U. S. Dept. Agr., pp. 1263–1306, 1 fig., 2 maps.
Describes irrigation from flowing and pumping artesian wells (p. 1293).

459 **Merrill** (Frederick J. H.). Bromine.
Mineral Resources U. S. for 1904, U. S. Geol. Survey, pp. 1029–1030.
Notes the occurrence of bromine in the brines of Michigan, Ohio, Pennsylvania, and New York.

460 **Miller** (Thomas D.). Texas oil fields.
Progressive Age, vol. 23, pp. 398–403, 1 fig.
Quotes R. T. Hill on agency of hot saline waters in the formation of the oil and gas pools of Texas and Louisiana; describes the encountering of oil in sinking an artesian well now flowing warm water at Corsicana, Tex.

461 **Mills** (W. M.). A physiographic and ecological study of the Winona Lake region.
Twenty-eighth Ann. Rept. Indiana Dept. Geol. and Nat. Res., pp. 377–396, Pls. VII–VIII, figs. 1–4.
Rich vegetation favored by springs (p. 384). Mentions post-Glacial conglomerate possibly cemented by spring water (p. 395).

462 **Mines and Minerals.** A 300-foot air-lift well plant at the Scranton Cold Storage House [Penn.].
Mines and Minerals, vol. 25, p. 494.
Describes an 835-foot well at this place.

463 **Mining and Scientific Press.** The Bassick mine, Querida, Colo.
Min. and Sci. Press, vol. 90, pp. 4–5, 1 fig.
Assigns the mineralization of the ore shoots to the action of thermal mineral springs along a line of fracture.

464 —— Unwatering the Comstock.
Min. and Sci. Press, vol. 90, pp. 65, 73–74, 1 fig.
Describes the filling of the lower levels by rising hot water and the work now being done to unwater the mines.

465 —— The Simplon tunnel.
Min. and Sci. Press, vol. 90, p. 119.
Mentions the encountering of large volumes of hot water in the construction of the tunnel.

466 —— Coolgardie, Australia, pumping system.
Min. and Sci. Press, vol. 90, pp. 120–122, 11 figs.
Contains a description of the use of well and saline mine waters for water supply during the early days of this gold field.

467 —— Artesian water.
Min. and Sci. Press, vol. 90, p. 168, 6 figs.
Discusses geological conditions essential to the securing of artesian water, and quotes I. C. Russell on the subject of legal restrictions on the waste of subsurface waters.

468 —— Water supply by compressed air.
Min. and Sci. Press, vol. 90, pp. 168–169.
Contains a description of the location, depth, etc., of the wells furnishing the additional water supply of Los Angeles, Cal.

469 —— The Simplon tunnel [between Switzerland and Italy].
Min. and Sci. Press, vol. 90, pp. 185–186, 7 figs.
Contains a description of the hot and cold springs encountered in drilling the tunnel.

470 **Mining and Scientific Press.** [Springs.]
Min. and Sci. Press, vol. 90, p. 231.
Discussion of the origin of springs.

471 —— [Ground-water level at Goldfield, Nev.].
Min. and Sci. Press, vol. 90, p. 348.
Notes the lack of water at Goldfield and the dependence on ground water, the level of which is found at 65–205 feet below the surface.

472 —— Value of geological knowledge.
Min. and Sci. Press, vol. 90, pp. 370–371, 1 fig.
Notes the varying amounts of underground water encountered in the different formations in sinking a shaft at the Illinois mine, Wisconsin.

473 —— Prospecting for desert mines.
Min. and Sci. Press, vol 90, p. 371, 1 fig.
Describes several springs in San Bernardino County, Cal.

474 —— Discovery and development of the Homestake mines of South Dakota.
Min. and Sci. Press, vol. 90, p. 404, 2 figs.
Describes the use in the Homestake mines of a stream of water issuing from a tunnel about 4 miles north of the works.

475 —— [Active mud volcano.]
Min. and Sci. Press, vol. 91, p. 119.
Notice of the breaking out of an active mud volcano early in August in the Black Rock Desert, Humboldt County, Nev.

476 —— At what depth do gold mines quit?
Min. and Sci. Press, vol. 91, p. 255.
Discusses the agency of descending mineral-bearing solutions in the secondary enrichment of gold veins.

477 —— [Theories of ore deposition.]
Min. and Sci. Press, vol. 91, p. 270.
Brief comparison of the lateral secretion and ascension theories.

478 —— The drainage of Cripple Creek mines.
Min. and Sci. Press, vol 91, p. 291, 1 fig.
Describes heavy inflow of water into the shafts and the present and proposed drainage tunnels. A figure is given showing the relation of the various shafts and tunnels to the present water level.

479 —— [Springs in the desert region of southwestern United States.]
Min. and Sci. Press, vol. 91, p. 293.
Describes several springs in California.

480 —— Divining rod as a water finder.
Min. and Sci. Press, vol. 91, p. 314.
Reprint from the Engineering News relating to the successful use of a divining rod at the Imperial Navy-Yard, Kiel, Germany.

481 —— What is a fissure vein?
Min. and Sci. Press, vol. 91, p. 392.
Discusses the alteration of rocks in veins by percolating mineral waters, the temperatures of mine waters, and the direction of flow of underground waters.

482 —— The Simplon tunnel.
Min. and Sci. Press, vol. 91, p. 399, 1 fig.
Describes the thermal springs encountered in the construction of the tunnel between Switzerland and Italy.

483 **Mining and Scientific Press.** [Mine water at Leadville, Colo.]
Min. and Sci. Press, vol. 91, p. 417.
Describes the trouble with mine water at Leadville, Colo.

484 **Mining Magazine.** Some questions regarding ore genesis.
Min. Magazine, vol. 12, pp. 399–400.
Discussion of the agency of water, volcanic and meteoric, in the formation of ore deposits.

485 **Mining Reporter.** The drainage of the Cripple Creek district [Colo.].
Min. Reporter, vol. 51, p. 280.
States that the lower depths of the Cripple Creek basin hold more water than the upper portions and gives the evidence on which this statement is based.

486 —— [Blowing wells.]
Min. Reporter, vol. 52, p. 285.
Brief description of blowing wells and explanation of their cause.

487 —— Drainage of the Cripple Creek district.
Min. Reporter, vol. 52, pp. 392–393, 2 figs.
Discusses the underground-water conditions in this district. Gives a map showing the relation of the present water level to the different mines.

488 —— The divining rod superseded.
Min. Reporter, vol. 52, p. 514.
Mentions the use of an electric or magnetic device in the location of ore bodies.

489 —— The Simplon tunnel.
Min. Reporter, vol. 52, pp. 595–596.
Notes the encountering of hot springs at 45° Centigrade in the construction of the tunnel between Switzerland and Italy.

490 **Minor** (J. C.). The so-called constipating effect of the hot water of Hot Springs, Ark.
Med. Mirror, St. Louis, vol. 16, no. 1, pp. 3–5.
Endeavors to disprove erroneous ideas concerning proportion of sulphur and injurious effects of this water.

491 **Minor** (John C., jr.). The production and modern uses of carbonic acid.
Chemical Engineer, vol. 1, pp. 212–218.
A paper read before the New York Section of the American Chemical Society, December 29, 1904. Contains a description of the wells at Saratoga Springs, N. Y., that are used for the production of this gas and describes the method used in separating the gas from the water.

492 **Mitchell** (George A.). Irrigation in the East.
The official proceedings of the Twelfth National Irrigation Congress at El Paso, Tex., November 15–18, 1904, pp. 346–348.
Mentions irrigation from flowing artesian wells near Atlantic City, N. J., and water supply from pumping 14 driven wells at Vineland, N. J.

493 **Monaghan** (J. F.). Windmills for South Africa.
Daily Consular Repts. no. 2210, Dept. Com. and Labor, p. 4.
Mentions necessity for sinking wells, owing to continued dry seasons.

494 **Moncrieff** (C. Scott). Irrigation.
Science, new ser., vol. 22, pp. 577–590.
Refers to irrigation by artesian wells in California, Algeria, and Queensland (p. 579), and by ordinary wells in India and elsewhere (p. 580).

495 **Monete** (Leon). The construction of the Simplon tunnel [between Switzerland and Italy].

Eng. Magazine, vol. 29, pp. 169–184, 29 figs.

Description of the springs of hot and cold water encountered in the construction of the tunnel is given. Photographs are given of two of these springs.

496 **Mooney** (Charles N.) and **Ayrs** (O. L.). Soil survey of the Greeneville area, Tennessee-North Carolina.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 493–525, 1 map, 1 fig.

Refers to occurrence of sink holes and effect on drainage (p. 498).

497 **Moore** (George T.). The use of copper sulphate as an algicide.

Jour. New England Waterworks Assoc., vol 19, pp. 474–481.

Notes the use of a thermal spring in Virginia, temperature given as 70° the year round, in the growing of water cress (pp. 475–476).

498 —— and **Kellerman** (Karl F.). Copper as an algicide and disinfectant in water supplies.

Bull. Bureau of Plant Industry, U. S. Dept. Agr., no. 76, 55 pp.

Describes injury of ground water stored in an open reservoir at Newtown, Pa., through growth of algæ, and disinfection of the water by use of copper sulphate (pp. 26–27).

498a **Moore** (Richard B.), **Schlundt** (Herman) and. Radio-activity of some deep-well and mineral waters.

Jour. Physical Chemistry, vol. 9, pp. 320–332.

See Schlundt (Herman) and Moore (Richard B.).

499 **Morgan** (Percy). The Hauraki gold fields, New Zealand.

Eng. and Min. Jour., vol. 79, pp. 861–862.

Contains discussion of the agency of underground water in the origin of the deposits.

500 **Morrison** (Charles E.). The importance of potable water supplies to mining communities.

Eng. and Min. Jour., vol. 80, pp. 1057–1058.

Includes a discussion of the availability of springs and wells in mining districts. Cites a case in Mexico in which a spring supply caused an epidemic due to the impregnation of the spring water by arsenic from the mining of a silver-lead ore carrying considerable arsenic.

501 **Moulthrop** (George E.). Annual address [of the president of the Montana Society of Engineers].

Jour. Assoc. Eng. Soc., vol. 35, pp. 141–163.

Notes the decision of March 3, 1903, of the Secretary of the Interior relating to the use of the reclamation fund in sinking artesian wells.

502 **Municipal Engineering**. Investigations of water supplies.

Municipal Engineering, vol. 28, pp. 23–24.

Contains a description of the subterranean gallery, deep- and driven-well system furnishing the water supply for the city of Indianapolis.

503 —— Removal of iron from ground water.

Municipal Engineering, vol. 28, pp. 472–477, 8 figs.

The water supply of Richmond, Mo., is taken from a group of 4 or 5 wells sunk to bed rock in the Missouri River bottom lands. The water contains 12 or more parts per million of iron. This article is devoted to a description of the method of aeration and filtration of this well water.

504 **Murphy** (E. C.). Drought in Ohio River drainage basin.

Water-Sup. and Irr. Paper no. 147, U. S. Geol. Survey, pp. 173–182.

Describes failure of springs and wells in Pennsylvania, West Virginia, and Kentucky, and the shortage of public supplies.

N.

505 **Neill** (N. P.), **Holmes** (J. Garnett) and. Soil survey of the Greeley area, Colorado.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 951-993, 1 map, 1 fig.

See Holmes (J. Garnett) and Neill (N. P.).

505a —— **Lapham** (Macy H.) and. Soil survey of the Solomonsville area, Arizona.

Field Operations of the Bureau of Soils, 1903, U. S. Dept. Agr., pp. 1045-1070, 1 fig., 1 map.

See Lapham (Macy H.) and Neill (N. P.).

506 **Newell** (Frederick Haynes). Proceedings of the second conference of engineers of the Reclamation Service; Organization; Report of Conference.

Water-Sup. and Irr. Paper no. 146, U. S. Geol. Survey, pp. 7-19.

Gives personnel of division of hydrology (pp. 7, 11) and notes papers on underground waters by W. C. Mendenhall and C. S. Slichter (p. 13).

507 **Nichols** (Francis H.). Notes from diary in China.

Bull. Am. Geog. Soc., vol. 37, pp. 339-356, 1 fig.

Describes the salt and gas wells of Tze Liu (pp. 349-350).

508 **Nicholson** (J. F.), **Lewis** (L. L.) and. A study of a few representative sources of drinking water.

Bull. Oklahoma Agr. Exp. Sta. no. 66, pp. 12-19.

See Lewis (L. L.) and Nicholson (J. F.).

509 **Noble** (T. A.), **Ross** (D. W.), **Whistler** (J. T.) and. Report of progress of stream measurements for the calendar year 1904: Part XII, Columbia River and Puget Sound Drainage.

Water-Sup. and Irr. Paper no. 135, U. S. Geol. Survey, 300 pp.

See Ross (D. W.), Whistler (J. T.), and Noble (T. A.).

510 **North Carolina,** Board of Health of. Tenth report, 1903-1904.

State laws of North Carolina relative to pollution of wells and springs (p. 79).

511 **Norton** (William Harmon). Iowa.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 220-225, 2 figs.

Describes the shallow and artesian water supplies of the various districts of the State, including the Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Cretaceous rocks. Lists the mineral springs of the State and notes the principal publications on underground waters.

512 —— Water supplies at Waterloo, Iowa.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 148-155.

The investigation was undertaken to discover underground supplies, the surface waters having caused a typhoid epidemic. The geology and water horizons, including the St. Peter sandstone, Oneota limestone, Jordan sandstone, etc., are described and predictions made as to the depth, quantity, quality, head, etc., to be expected in a deep well. (The prediction has since been verified in every particular by the well sunk as a result of Professor Norton's recommendations. M. L. F.)

O.

513 **O'Harra** (C. C.), **Darton** (N. H.) and. Description of the Aladdin quadrangle [Wyoming-South Dakota-Montana].

Geologic Atlas U. S., folio 128, U. S. Geol. Survey, 8 pp., 4 maps, 1 col. sect., 1 fig.

See Darton (N. H.) and O'Harra (C. C.).

514 **Oliphant** (F. H.). Petroleum.

Mineral Resources U. S. for 1904, U. S. Geol. Survey, pp. 675–759.

Describes the occurrence of salt water in the oil wells of Louisiana (p. 708), Texas (pp. 712, 713, 714), Russia (p. 733), Germany (p. 742), and China (p. 757).

515 —— Natural gas.

Mineral Resources U. S. for 1904, U. S. Geol. Survey, pp. 761–788.

Describes the occurrence of water in the gas wells of Indiana (p. 772) and Texas (p. 785). Notes that many of the artesian wells along the Gulf coast give off considerable natural gas with the artesian water (p. 785).

P.

516 **Pagliucci** (Frank D.). The quicksilver deposits of Huitzuco [Mexico].

Eng. and Min. Jour., vol. 79, pp. 417–418, 2 figs.

The workings follow an old hot-spring conduit or geyser pipe. The relation of the quicksilver deposits to this conduit are discussed.

516a **Palache** (Charles), **Jaggar** (Thomas A., jr.) and. Description of the Bradshaw Mountains quadrangle [Arizona].

Geologic Atlas U. S., folio 126, U. S. Geol. Survey, 11 pp., 4 maps, 1 illus. sheet.

See Jaggar (Thomas A., jr.) and Palache (Charles).

517 **Palmer** (Charles S.). The replacement of quartz by pyrite.

Eng. and Min. Jour., vol. 79, p. 169.

Discusses the agency of hot alkaline waters in the replacement of quartz by pyrite.

518 **Pammel** (L. H.) and **Fogel** (Estelle D.). Some railroad water supplies.

Proc. Iowa Acad. Sci. for 1904, vol. 12, pp. 151–155.

Gives the location and depth of wells and temperatures and sanitary analyses of the waters of wells in the drift and St. Peter sandstone of Iowa.

519 **Park** (Emma J.) and **Lyman** (Kate). The Springfield water supply: Description of springs and the geology of the district.

Bull. Bradley Geol. Field Sta. of Drury Coll., vol. 1, pt. 2, pp. 45–49.

Describes in some detail the springs used for public supply at Springfield, Mo. The water issues from the contact of the Upper and Lower Burlington limestones, but part may come from the St. Peters sandstone along a near-by fault. The sinks and caverns of the region are mentioned and the question of pollution of the limestone waters considered.

520 —— The Hannibal formation in Greene County [Missouri].

Bull. Bradley Geol. Field Sta. of Drury Coll., vol. 1, pt. 2, pp. 79–90.

Describes springs from contact of Lower Burlington and Chouteau limestones, the water coming from large solution passages or caves (p. 81). The composition of the well and spring waters from the Hannibal formation are considered and analyses of the water given (p. 87–88).

521 **Park** (James). Ore deposits in relation to thermal activity.

Eng. and Min. Jour., vol. 79, pp. 606–607; continued on pp. 700–701.

These articles are abstracts from "Mining geology," by Prof. James Park, in the Australian Mining Standard, January 26, 1905. Describes in considerable detail the relations of hot springs and fumaroles to ore deposits.

522 —— Metasomatic replacement.

Eng. and Min. Jour., vol. 79, p. 799.

This article is an abstract from "Mining geology," by Prof. James Park, in the Australian Mining Standard, January 26, 1905. Discussion of mineral solutions in metasomatic replacement given in considerable detail.

523 **Park** (James). Contact metamorphic deposits.

Eng. and Min. Jour., vol. 79, pp. 896.

Contains discussions of the agency of underground water in contact metamorphism. This article is an abstract from "Mining geology," by Prof. James Park, in the Australian Mining Standard, February 16, 1905.

524 —— The formation of veins.

Eng. and Min. Jour., vol. 79, pp. 941–942.

This article is an abstract from "Mining geology," by Prof. James Park, in the Australian Mining Standard, February 23, 1905. The agency of underground waters in the formation of veins is discussed.

525 —— Theories of vein formation.

Eng. and Min. Jour., vol. 79, pp. 993–994.

Discusses the eruptive after-action, lateral-secretion, and ascension theories. This article is an abstract from "Mining geology," by Prof. James Park, in the Australian Mining Standard, February 16, 1905.

526 —— Absorption of metals by silica and clays in relation to ore deposition.

Eng. and Min. Jour., vol. 79, p. 1242.

Discusses the power of clays, etc., of extracting metals from mineralized underground waters.

527 [**Peale**, A. C.] Mineral waters.

Mineral Resources U. S. for 1904, U. S. Geol. Survey, pp. 1185–1208.

Both production and value show a large gain over 1903. The production is given as 67,718,500 gallons and the value as $10,398,450. A list of the commercial springs is given. A list of the mineral waters on exhibition at the Louisiana Purchase Exposition is given. Tables showing the imports of mineral waters from 1867 to 1904 and exports from 1875 to 1883 are also given.

528 **Peary** (Robert E.). Address delivered at the annual meeting of the American Geographical Society, January 24, 1905.

Bull. Am. Geog. Soc., vol. 37, pp. 129–143.

Notes the sinking of artesian wells in the Algerian Sahara, and briefly discusses the underground-water conditions and the use of the water in irrigation (p. 137).

530 **Pendell** (George). Pumping plants and irrigation at El Paso, Tex.

Irrigation Aid, vol. 1, no. 6, p. 8.

Mentions several wells from which water is used for irrigation.

531 **Perkins** (F. C.). Latest electrical equipment of the Karawanken tunnel [Austria-Hungary].

Min. and Sci. Press, vol. 91, p. 275.

Notes the encountering of a considerable amount of water in the excavation of the tunnel.

532 **Perkins** (George H.). Vermont.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 60–67, 1 fig.

Discusses public supplies from springs and gives table (pp. 60–62); discusses common and mineral springs and gives analyses and list of commercial springs (pp. 62–64). Describes distribution of ordinary, deep, and artesian wells and gives map (pp. 64–65). Emphasizes the abundance of water (pp. 66–67). Gives list of publications (p. 67).

533 **Perkins** (W. R.), **Logan** (W. N.), and. The underground waters of Mississippi.

Bull. Mississippi Agr. Exp. Sta. no. 89, 112 pp., 23 figs.

See Logan (W. N.) and Perkins (W. R.).

534 **Philips** (William Battle). The quicksilver deposits of Brewster County, Tex.

Econ. Geol., vol. 1 pp. 155–162.

Describes caverns in the Upper Cretaceous and their contained cinnabar deposits (p. 158).

535 **Pittman** (E. F.) and **David** (T. W. E.). Irrigation geologically considered with special reference to the artesian area of New South Wales.

Jour. and Proc. Roy. Soc., N. S. Wales, eng. sect., vol. 37, pp. cili–cliii, 2 pls. Abstract: Exp. Sta. Record, vol. 17, no. 2, p. 193.

Summarizes present state of knowledge and gives list of papers bearing on the subject.

536 **Porter** (Rufus K.). Timber tunneling in quicksand.

Jour. Assoc. Eng. Soc., vol. 35, pp. 61–76, 11 figs.

Describes the methods used in driving a timber tunnel in quicksand at Newton, Mass., 10 feet below the ground-water level. Contains descriptions of the water encountered and how it was disposed of.

537 —— Driving a tunnel in quicksand.

Mines and Minerals, vol. 26, pp. 219–221, 10 figs.

Describes the method used in driving a tunnel in quicksand at Newton, Mass., where the level of ground water was 10 feet above grade.

538 **Potter** (Alexander). Breakage in sewer conduits; its cause, effect, and prevention.

Jour. Assoc. Eng. Soc., vol. 35, pp. 190–213.

Discusses the admission of ground water into sewers through defective pipes. Notes that in one case such inflow caused a lowering of the ground-water table.

539 **Pratt** (Joseph Hyde) and **Lewis** (Joseph Volney). Corundum and the peridotites of western North Carolina.

North Carolina Geol. Survey, vol. 1, 464 pp., 45 pls., 35 figs.

Mentions relation of peridotite weathering to percolation of water (p. 65); describes leaching effect of infiltrating waters (p. 113), relations of serpentinization to zone of hydration (pp. 118–121), of chloritization to infiltrating solutions (p. 123); mentions hypothesis for formation and alteration of corundum through agency of percolating and permeating waters (pp. 270, 340, 341, 347).

540 **Pressey** (Henry A.). Water powers of the southern Appalachian region.

Forestry and Irrigation, vol. 11, pp. 498–512, 5 figs.

Mentions the existence of many springs on the mountains and discusses the relation of forests to springs and stream flow.

541 **Pumpelly** (Raphael W.). "Physiographic observations between the Syr Darya and Lake Kara Kul, on the Pamir, in 1903."

Explorations in Turkestan with an account of the basin of eastern Persia and Sistan—Carnegie Institution of Washington, 1905, pp. 123–155, 38 figs, 2 maps.

Notes absorption of water of mountain streams in the sands of the Kara Kul desert (p. 132).

542 **Purdue** (A. H.). Northern Arkansas.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 188–197, 1 pl., 2 figs.

Describes the underground-water conditions in the Boone chert area, in the Boston Mountains area, in the Paleozoic area, and in the Tertiary region, discussing conditions for wells. Enumerates the mineral springs and the principal publications bearing on underground waters in that part of the State.

543 **Purdue** (A. H.). Water resources of the Winslow quadrangle, Arkansas.
Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 84–87.
Describes the underground-water conditions and discusses the quantity and quality of the supplies of wells and springs in the Boone and Pitkin limestones, Hall sandstone, and Winslow sandstones and shales. One sulphur spring is described.

544 —— Water resources of the contact region between the Paleozoic and Mississippi embayment deposits in northern Arkansas.
Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 88–119.
Discusses the topography and geology of the region, and considers the underground-water supplies from the Ordovician beds, Boone formation, Batesville sandstone, Pitkin limestone, and Morrow formation of the highlands, and of the Tertiary and later horizons of the lowlands. The derivation of water from rainfall, the conditions of absorption from rivers, and the source from underlying Paleozoic rocks are considered. The water horizons are not continuous and flows are not to be expected. The composition of the water, methods of sinking wells, capacity, and sanitary location of wells are also discussed.

545 **Pynchon** (W. H. C.). Drilled wells of the Triassic area of the Connecticut Valley.
Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 65–94, 2 figs.
Describes a considerable number of wells, and the relation of the occurrence of water to the geology. Emphasizes the uniform water-bearing character of the sandstones, the high percentage of mineral matter, and the general absence of flowing wells. Gives analysis and many brief records.

R.

546 **Rafter** (George W.). Hydrology of the State of New York.
Bull. New York State Mus. no. 85, 902 pp., 45 pls., 74 figs., 5 maps.
Discusses relation of rainfall to run-off, including effect on level and fluctuation of water table (pp. 114–203), and relation of geologic structure to run-off (pp. 162–172). Mentions use of wells in New York City (pp. 676–679). Describes relations of open and driven wells on Long Island for the Borough of Brooklyn (pp. 681–693), and discusses the unfavorable conditions for such supplies elsewhere in the State (pp. 713–717). Describes supplies obtained from wells and springs in western New York (pp. 844–863).

547 **Ransome** (Frederick Leslie). The present standing of applied geology.
Econ. Geol., vol. 1, pp. 1–10.
Considers briefly the relative importance of meteoric and magmatic waters, and quotes Becker on artesian origin of the hot waters of the Comstock lode (p. 8).

548 —— **Lindgren** (Waldemar) and. The geologic resurvey of the Cripple Creek district, Colorado.
Bull. U. S. Geol. Survey no. 260, pp. 85–98.
See Lindgren (Waldemar) and Ransome (Frederick Leslie).

549 **Read** (Thomas Thornton). The phase rule and conceptions of igneous magmas. Their bearing on ore deposition.
Econ. Geol., vol. 1, pp. 101–118
Considers the relative importance of meteoric and magmatic waters (pp. 101–102) and the origin of the latter (pp. 101, 117).

550 —— Platinum and palladium in certain copper ores.
Eng. and Min. Jour., vol 79, pp. 985–986, 3 figs.
Contains a discussion of the agency of mineralized underground waters in the formation of chalcopyrite, covellite, and chalcocite.

551 **Reagan** (Albert B.). Some geological observations on the central part of the Rosebud Indian Reservation, South Dakota.

Am. Geologist, vol. 36, pp. 229–243.

Notes the occurrence of sinks and springs, and considers the composition of spring and well waters. A map of some of the sinks is given. The waters are from Cretaceous and Tertiary deposits (pp. 240–241).

552 **Reid** (John A.). Some underground waters and their work.

California Jour. Technology, vol. 5, pp. 117–121, 7 figs.

Discusses the agency of the thermal waters of the Comstock Lode, Nevada, in the decomposition of the country rock and the deposition of the ores. Several analyses of mine waters are given.

553 —— Structure and genesis of the Comstock Lode.

Min. and Sci. Press, vol. 91, p. 244.

An extended discussion of the agency of mineral solutions in the formation of the ore deposits of the Comstock Lode.

554 —— Some underground waters and their work.

Min. Reporter, vol. 51, pp. 642–644, 7 figs.

Gives analysis of several Nevada mine waters and discusses the alteration of rocks by heated mineral waters.

555 —— The structure and genesis of the Comstock Lode. [Nevada.]

Bull. Dept. Geol., Univ. Cal., vol. 4, no. 10, pp. 177–199.

Discusses the agency of underground waters in ore deposition; gives analyses and assays of the deep and vadose waters of the mines.

556 **Rice** (Thomas D.) and **Geib** (W. J.). Soil survey of the Gainesville area, Florida.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 269–289, 1 map, 1 fig.

Describes sink holes and limestone caverns (p. 274).

557 —— and **Geib** (W. J.). Soil survey of Warren County, Kentucky.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 527–541, 1 map, 1 fig.

Describes the occurrence of sink holes and their connection with limestone caverns (p. 530).

558 —— and **Griswold** (Lewis). Soil survey of Acadia Parish, Louisiana.

Field Operations of the Bureau of Soils, 1903, U. S. Dept. Agr., pp. 461–485, 1 fig., 1 map.

Describes irrigation from wells sunk to the Lafayette formation, and states that a few of the wells are flowing. Describes the geological occurrence of the water and the change from fresh water to salt water by continued pumping in time of drought (pp. 477–478).

558a **Richards** (Ellen H.) and **Woodman** (Alpheus G.). Air, water, and food from a sanitary standpoint.

New York and London, 1904, 262 pp., 13 figs., 1 map.

Gives analytical procedure for the sanitary examination of waters, and discusses particularly the interpretation of the analytical data obtained by the examination of well water.

559 **Richardson** (George B.). Salt, gypsum, and petroleum in trans-Pecos, Texas.

Bull. U. S. Geol. Survey no. 260, pp. 573–585.

Notes the relation of the ground-water level to salt deposits (p. 580), considers the occurrence of artesian water and wells (p. 581), gives well record (p. 583), and describes caves and channels in gypsum (p. 585).

560 **Richardson** (George B.). Native sulphur in El Paso County, Texas.
Bull. U. S. Geol. Survey no. 260, pp. 589–592.
Describes the shallow mineralized waters (p. 590) and notes the deposition of gypsum by the evaporation of the ground waters (p. 590). Caves in gypsum are also mentioned (p. 591).

561 **Riemer** (W. H. V.). An experiment and an experience in sewage disposal.
Municipal Engineering, vol. 29, pp. 252–253.
Discusses the difficulties encountered in the management of the sewage plant due to the reduced amount of ground water entering the sewers.

562 **Rix** (Edward A.). Compressed air on the Pacific coast.
Mines and Minerals, vol. 25, pp. 465–472, 15 figs.
Notes the encountering of a large flow of water in the Brunswick mine, Grass Valley, California (p. 468); describes the use of compressed air in increasing the flow of an artesian well at Tulare (pp. 469–470); describes the pumping plant of the Los Angeles well system (p. 470).

563 **Roadhouse** (J. E.). Irrigation conditions in Imperial Valley, California.
Bull. Office of Exp. Sta., U. S. Dept. Agr., no. 158, pp. 175–194, 1 pl.
Describes seepage and its relation to loss of water from canals (pp. 186–189).

564 **Roberts** (L. H.). Watering the desert: A short history of the 300-mile pipe system supplying water to the Coolgardie gold fields and district in Australia.
Technical World Magazine, vol. 3, pp. 85–86, 3 figs.
Notes the encountering of salt water in mines.

565 **Root** (Aldert S.), **Mackie** (W. W.), **Lapham** (Macy H.), and. Soil survey of the Sacramento area, California.
Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 1049–1087, 1 map, 1 fig.
See Lapham (Macy H.), Root (Aldert S.), and Mackie (W. W.).

566 **Ross** (Berta). Hahatonka [Missouri].
Bull. Bradley Geol. Field Sta. of Drury Coll., vol. 1, pt. 2, pp. 68–71.
Describes Hahatonka and other springs, sinks, caves, underground channels, and natural bridge, together with cave deposits. The proposal to utilize the spring for power is noted, the result of damming on the underground drainage, and the possible opening of new outlets considered.

567 **Ross** (D. W.), **Whistler** (J. T.), and **Noble** (T. A.). Report of progress of Stream measurements for the calendar year 1904: Part XII, Columbia River and Puget Sound drainage.
Water-Sup. and Irr. Paper no. 135, U. S. Geol. Survey, 300 pp.
Gives discharge of the following Idaho springs (pp. 271–273) and considers the use of several for irrigation: Bear, Big, Blue, Caldwell, East Bald Cabin, West Bald Cabin, Garner, Golf, Green, Grizzly, Hawley, Rock, Sherwood, Thompson, Thurman, and Whitman.

568 **Rowe** (Jesse Perry). Montana gypsum deposits.
Am. Geologist, vol. 35, pp. 104–113.
Notes the presence of calcium sulphate and the deposition of gypsum by springs in Montana.

569 **Russell** (Israel C.). Preliminary report on the geology and water resources of central Oregon.
Bull. U. S. Geol. Survey no. 252, 138 pp., 24 pls., 4 figs.
Mentions large springs in river beds (pp. 18–19); describes indurating effect of silica waters (p. 32); describes conditions relative to artesian areas and wells (pp. 56–122); describes thermal and normal springs (pp. 41, 55–96), drilled wells (p. 41), deep driven wells (p. 84), horizontal wells (pp. 66, 79), and gives well records (pp. 42, 84).

570 **Russell** (Israel C.). A geological reconnaissance along the north shore of Lakes Huron and Michigan.

Ann. Rept. Michigan Geol. Survey, 1904, pp. 33–114, 11 pls., 1 fig., 3 maps.

Describes knob and kettle topography due to solution of gypsum beds (p. 44) and formation of breccia by settling of overlying beds (p. 45).

571 —— The influence of caverns on topography.

Science, new ser., vol. 21, pp. 30–32.

Describes hills left in relief owing to subterranean drainage, and gives examples at Luray, Va., at Mackinac Island, Michigan, and at Gibraltar.

572 **Rutherford** (Rutledge). Rice Cultivation in America.

Technical World Magazine, vol. 4, pp. 234–240, 7 figs.

Describes the use of artesian-well water in the irrigation of rice fields of southern United States.

S.

573 **San Antonio Gazette.** Irrigation in artesian belt.

Irrigation Aid, vol. 3, no. 1, pp. 9–12.

Gives a description of the wells, springs, and underground-water conditions in southwestern Texas.

574 **Sanchez** (Alfred M.). Soil survey of the Provo area, Utah.

Field Operations of the Bureau of Soils, 1903, U. S. Dept. Agr., pp. 1121–1150, 1 fig., 3 maps.

Gives a map (Map 65) showing the depth to the water table and discusses depths and relation to alkali and seepage (pp. 1138–1141). Mentions irrigation by flowing wells (p. 1134).

575 **Savage** (T. E.). Geology of Benton County [Iowa].

Ann. Rept. Iowa Geol. Survey, 1904, vol. 15, pp. 127–225, 14 figs., 1 map.

Mentions shallow wells, springs, flowing artesian wells, and well water for town and farm use (p. 224).

576 **Schardt** (H.) [in Engineering Magazine]. The geology of the Simplon tunnel [between Switzerland and Italy].

Min. Reporter, vol. 52, p. 314.

Contains a description of the springs encountered in the construction of the tunnel.

577 **Scherer** (George H.). Geology of the Hahatonka district, Camden County [Missouri].

Bull. Bradley Geol. Field Sta. of Drury Coll., vol. 1, pt. 2, pp. 58–67.

Considers part of hot ground waters accompanying pegmatite intrusion in formation of chert (p. 60), describes springs and wells of the Decaturville "dome" (pp. 62–63), discusses availability of springs for water power (p. 63), and gives well records and analyses (pp. 63–67).

578 **Schlundt** (Herman) and **Moore** (Richard B.). Radio-activity of some deep-well and mineral waters.

Jour. Physical Chemistry, vol. 9, pp. 320–332.

Describes methods and gives results of experiments on the radio-active properties of deep-well and spring waters in the limestone near Columbia, Mo. The location, depth, and method of pumping the wells are given.

579 **Schoch** (Edward R.). The genesis of the Tarkwa Banket. [Gold Coast, Africa.]

Eng. and Min. Jour., vol. 79, pp. 1235–1236.

Discusses the agency of mineral-bearing solutions in the formation of these deposits.

580 **Schrader** (F. C.) and **Haworth** (Erasmus). Oil and gas of the Independence quadrangle, Kansas.

Bull. U. S. Geol. Survey no. 260, pp. 446–458.

Gives summary of drilling in 1904.

581 **Schultz** (Alfred R.). Wisconsin district.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 233–241, 2 figs.

Describes the underground-water resources of the State and the occurrence of water in the Potsdam sandstone, Lower Magnesian limestone, St. Peter sandstone, Galena-Trenton limestone, Niagara limestone, and drift deposits. Describes the occurrence of springs and mineral waters and lists the important mineral springs. Notes several publications on underground waters.

582 **Schwarz** (T. E.). Features of the occurrence of ore at Red Mountain, Ouray County, Colorado.

Bimonthly Bull. Am. Inst. Min. Eng. no. 2, pp. 267–274, 3 figs.

Ascribes the origin of the Yankee Girl ore body to secondary enrichment by descending acid solutions, and quotes W. H. Weed as explaining the occurrence of enargite in the Butte mines as a secondary product deposited by ascending alkaline solutions.

583 **Science.** [Review of notes on the spring waters of Massachusetts, published in "Contributions to the Hydrology of eastern United States, 1903"].

Science, new ser., vol. 21, pp. 279–280.

Notes economic value and distribution of springs and cooperation of drillers.

584 —— [Notes on the work of the division of hydrology of the U. S. Geological Survey].

Science, new ser., vol. 21, pp. 319–320.

Compares this division with similar divisions in other countries, and notes the establishment of such bureaus in Brazil and Peru.

585 —— [Investigation of "blowing" or "breathing" wells].

Science, new ser., vol. 22, pp. 415–416.

Refers to breathing wells in Nebraska and Louisiana, and attributes their peculiarity changes in atmospheric pressure or temperature.

586 —— [Ground water in crystalline rocks in Connecticut].

Science, new ser., vol. 22, p. 476.

States that the water is frequently under artesian pressure, and bears a definite relation to the drift.

587 **Scientific American.** The dangers and difficulties of tunnel boring.

Compressed Air, vol. 10, pp. 3633–3634.

Mentions the encountering of hot springs in the Simplon tunnel between Switzerland and Italy.

588 —— An explanation of ice caves.

Sci. Am. vol. 92, p. 479.

Describes results recently obtained from experiments by Schwalbe.

589 **Scientific American Supplement.** Composition of gases from mineral springs, helium, etc., and radio-activity.

Sci. Am. Supp., vol. 59, pp. 24294–24295.

Describes the results obtained from a study of the radio-active gases of several European springs.

590 —— [Removal of iron from subterranean water.]

Sci. Am. Supp., vol. 60, p. 24875.

Describes the removal of iron from the subterranean water supply of Berlin, Germany. The water is taken from 25 wells on the shore of Lake Tegel.

591 **Shamel** (Charles H.). The American law relating to minerals.

School of Mines Quarterly, Columbia Univ., vol. 27, pp. 1–27.

Discusses the law relating to underground waters. Many citations are given (pp. 17–19, 22).

592 **Shepard** (Edward M.). Spring system of the Decaturville Dome, Camden County, Mo.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 113–125, 4 figs.

Describes a line of springs surrounding the Dome and the radiation of their channels from the center of the Dome. Describes many springs, sink holes, and artesian wells. Gives water analysis.

593 —— Missouri.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 209–219, 3 figs.

Describes the underground-water resources of the Northwestern Plateau district, North-central Plain district, the Ozark-St. Francis Dome, and the Southeastern lowlands, describing in detail numerous springs, wells, and water-bearing formations. Lists the important mineral springs and publications relating to underground waters of the State.

594 ——The New Madrid earthquake.

Jour. Geol., vol. 13, pp. 45–62.

This paper is a discussion of the New Madrid earthquake and the relation of some of its phenomena to artesian conditions. Among the subjects considered are the extrusion of water or mud by the quake (pp. 46, 47, 57, 58), artesian wells at Memphis Tenn., Jackson, Miss., and at points in Kentucky, Missouri, and Arkansas (p. 53), springs and discharged sands (pp. 54, 56), relation of earthquake to artesian conditions (pp. 59, 61, 62), and the effect of recent earthquakes on wells (p. 59) and springs (p. 60).

595 **Sherman** (Charles W.). Waterworks statistics for the year 1904, in form adopted by the New England Waterworks Association.

Jour. New England Waterworks Assoc., vol. 19, pp. 241–263.

Gives references to previous compilations of statistics (pp. 241–243). Many towns are listed which derive their supply from wells and springs.

596 **Shnable** (E. R.). A criticism of timber specifications and a suggested method of recording earth borings.

Eng. News, vol. 53, p. 20.

Presents two forms of recording borings and suggests the keeping of time consumed in passing through each strata.

597 **Siebenthal** (C. E.). Structural features of the Joplin district [Missouri].

Econ. Geol., vol. 1 pp. 119–128.

Discusses the formation of caverns by solution and the development of underground-drainage systems, and suggests the settling of the roofs of the caverns as the cause of some of the faulting (pp. 127–128).

598 **Skinner** (S. A.). Some observations on the use of alkaline waters for laundry purposes.

Jour. Am. Chem. Soc., vol. 27, pp. 165–167.

Describes the use of a strongly alkaline artesian water in a steam laundry and the difficulties encountered. An analysis of the water is given. A large amount of free ammonia is noted, and it is stated that "Wanklyn and Chapman, in their treatise on water analysis, are authority for the statement that such a condition is sometimes met with in deep waters that are organically pure."

599 **Slichter** (Charles S.). Description of underflow meter used in measuring the velocity and direction of movement of underground water.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 17–31, 4 pls., 8 figs.

Describes a method of measurement by means of test wells and an electrical device by which the velocity of a certain salt in the water is measured.

600 —— The California or "Stovepipe" method of well construction.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 32–36, 3 figs.

Mentions a system of perforating the casings at horizons where water is known to occur.

601 —— Approximate methods of measuring the yield of flowing wells.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 37–42, 2 figs.

Describes and gives tables for a method of calculation by measuring the height or lateral projection of a jet of water.

602 —— Field measurements of the rate of movement of underground waters.

Water-Sup. and Irr. Paper no. 140, U. S. Geol. Survey, 122 pp.

Discusses the capacity of sand to transmit water and describes laboratory experiments on the flow in sands and gravels. The use of the underflow meter is considered in detail and the results of measurements of underflows in California and New York given. Attention is paid to the specific capacity of wells as shown by tests, to the tests of typical pumping plants in Texas and New Mexico, and to the California or "stovepipe" method of well construction.

603 —— Observations on the ground waters of Rio Grande Valley.

Water-Sup. and Irr. Paper no. 141, U. S. Geol. Survey, 83 pp.

Describes the underflow conditions near El Paso, Tex., illustrates various methods of drilling, considers the methods, results, and cost of pumping and the resultant lowering of the water table, and gives a number of analyses of the ground waters.

604 —— The underflow of the Arkansas River.

Abstract: Science, new ser., vol. 21, p. 957.

Discusses variation in rate of underflow, and connection of the movement with the river.

605 **Smith** (Erastus G.). The Mississippi River as the source of water supply for the inhabitants of the Mississippi Valley.

Jour. New England Waterworks Assoc., vol. 19, pp. 215–231.

Notes the calcareous nature of the glacial drift in the Mississippi Valley and the resulting hard river and surface well waters in this section (pp. 217–218).

606 **Smith** (Eugene Allen). Alabama.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 164–170, 1 pl.

Describes the occurrence of underground water in the Cambrian and Carboniferous rocks, and artesian conditions in the various Cretaceous and Tertiary formations, illustrating artesian areas by a map. Notes the occurrence of brine wells. Gives list of mineral springs and of publications on underground waters of the State.

607 —— and **McCalley** (Henry). Index to the mineral resources of Alabama.

Alabama Geol. Survey. 1904, 79 pp., map and 6 pls.

Refers to relation of water level to character of gold ores (p. 54); mentions occurrence of salt water under artesian pressure in gas wells and "seeps," and use of the salt (pp. 71–72), and enumerates commercial mineral springs and artesian wells, stating the class of water (pp. 72–73).

608 **Smith** (George Otis). Water resources of the Portsmouth-York region, New Hampshire and Maine.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 120–128.

Describes the occurrence of water in the drift of the valleys and in the joints of schists, slates, quartzites, etc. The wells are generally successful and some flow. The confinement is ascribed to the constriction of the joints and a partial cementation near the surface. Dikes are to be avoided in sinking wells.

609 —— Water supply from glacial gravels near Augusta, Me.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 156–160.

Gives the results of an investigation of certain ponds and springs which it was proposed to utilize for water supply. It was found that the ponds occupied a sort of gravel basin draining underground through the springs and no additional supply would be obtained by using both over that obtained from the springs alone.

610 —— Artesian development in Washington, Atanum-Moxee Valley.

Irrigation, vol. 3, no. 5, pp. 6–7, 1 fig.

Discusses the artesian conditions existing in the Atanum-Moxee Valley.

611 —— Artesian water in crystalline rocks.

Abstract: Science, new ser., vol. 21, pp. 224–225.

Discusses the confinement of water due to cementation of the rock fissures near the surface, and consequent flowing and nonflowing artesian wells near York, Me.

612 **Smith** (Herbert E.). Report on investigation of river pollution and water supplies.

Twenty-seventh Ann. Rept. State Board of Health of Connecticut, 1904, pp. 217–231.

Summarizes work of analyzing well and spring water, and gives many sanitary analyses.

613 **Smith** (William G.) and **Meeker** (F. N.). Soil survey of Sumter County, Alabama.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 317–342, 1 map, 1 fig.

Summarizes distribution of artesian wells in the county (p. 321).

614 **Smith** (William Sidney Tangier). Lead, zinc, and fluorspar deposits of western Kentucky: Part II, Ore deposits and mines.

Prof. Paper U. S. Geol. Survey no. 36, pp. 107–218, 8 pls., 31 figs.

Advocates origin of the deposits through agency of ore-bearing solutions ascending along fault planes (pp. 150–154). Mentions sink holes and ore deposition along faults (pp. 172, 178) and unequal penetration of limestone by ore-bearing solutions (p. 178).

615 —— Water resources of the Joplin district, Missouri-Kansas.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 74–83.

In addition to the discussion of general underground-water conditions, the paper describes the numerous large springs, some of which occur on fault lines, and the deep borings for ore or water, one of which is 2,005 feet deep. Analyses of spring and well waters are given. The waters are often contaminated by mine waters.

616 **Smyth** (C. H., jr.). Replacement of quartz by pyrite and corrosion of quartz pebbles.

Am. Jour. Sci., 4th ser., vol. 19, pp. 277–285, 1 fig., 1 plate.

Discusses the agency of hot alkaline mineralized solutions in the replacement by pyrite of the quartz pebbles of the Oneida conglomerate in central New York.

617 **Smyth** (H. L.). The origin and classification of placers
Eng. and Min. Jour., vol. 79, pp. 1045–1046.
Discusses the agency of underground waters in the decay of rocks and the alteration of ore deposits.

618 **Snow** (T. W.). Water softening for boiler use.
Jour. West. Soc. Eng., vol. 10, pp. 745–759, 9 figs.
Gives two analyses of well water at Bismarck, Mo. (pp. 748–749).

619 **Spencer** (Arthur Coe). The magmatic origin of vein-forming waters in southeastern Alaska.
Bimonthly Bull. Am. Inst. Eng. no. 5, pp. 971–978.
Discusses magmatic waters in general; includes many references to similar papers; ascribes the veins of southeastern Alaska to the agency of magmatic waters, and quotes Lindgren on a similar origin of the California gold-quartz veins.

620 —— The Treadwell ore deposits, Douglas Island.
Bull. U. S. Geol. Survey no. 259, pp. 69–87.
Mentions the part taken by water in vein alteration (p. 84) and considers the source of the waters (p. 86).

621 **Spoon** (W. L.). Building sand-clay roads in Southern States.
Yearbook U. S. Dept. Agr., 1903, 259–266, 2 pls., 3 figs.
Discusses conditions of saturation and drainage of roads due to different proportions of clay and sand (pp. 260–261).

622 **Spurr** (Josiah Edward). Genetic relations of the western Nevada ores.
Bimonthly Bull. Am. Inst. Min. Eng. no. 5, pp. 939–969.
Discusses the agency of mineralized underground waters in the formation of the ore deposits.

623 —— Enrichment in fissure veins.
Eng. and Min. Jour., vol. 80, pp. 597–598.
Discusses the agency of ascending and descending solutions in the enrichment.

624 —— Tonopah mining district [Nevada].
Jour. Franklin Institute, vol. 160, no. 1, pp. 1–20, 10 figs., 1 map.
Discusses the agency of circulating mineralized underground waters in the formation of the veins and ore deposits; describes the channels followed by the mineralized solutions and the alteration and silicification of the country rock; notes the irregularity of surface oxidation due to the fact of there being no regular ground water.

625 —— The ores of Goldfield, Nev.
Bull. U. S. Geol. Survey no. 260, pp. 132–139.
Notes deposition of ores by hot spring action (pp. 134–139).

626 —— Developments at Tonopah, Nev., during 1904.
Bull. U. S. Geol. Survey no. 260, pp. 140–149.
Describes the use of well and shaft for collecting water for town supply and considers the character of the water zone (p. 141). The part of water in vein formation and alteration is also noted (p. 146).

627 —— Geology of the Tonopah mining district, Nevada.
Prof. Paper U. S. Geol. Survey no. 42, 295 pp., 24 pls., 78 figs.
Discusses alteration of andesite by thermal waters (pp. 207–252) and formation of mineral veins along circulation channels (p. 83). Discusses the probable nature and composition of the mineralizing waters (pp. 85, 104, 227, 235–237, 250, 253–260) and changes in composition owing to mineral deposition (pp. 235–237). Describes water zones (p. 107) and irregular distribution of water encountered in mines (p. 105) in connection with porosity and absorption (p. 107). Discusses the origin of hot and cold springs (pp. 254–260), and describes solfataras and fumaroles (pp. 260–261). Describes investigations regarding increase of temperature with depth (pp. 263–266). Notes the formation of gypsum by oxidizing waters (p. 94).

628 **Spurr** (Josiah Edward) and **Garry** (G. H.). Preliminary report on ore deposits in the Georgetown, Colorado, mining district.

Bull. U. S. Geol. Survey no. 260, pp. 99–120.

Refers briefly to the part of water in ore deposition (pp. 113–115) and to the depth of oxidation.

629 **Stanton** (Timothy W.) and **Hatcher** (J. B.). Geology and paleontology of the Judith River beds.

Bull. U. S. Geol. Survey no. 257, pp. 1–66.

Quotes Grinnell and Dana on action of water in producing landslips in Montana (p. 34).

630 **Steiner** (Charles R.). Impregnation of sand and gravel deposits with cement.

Eng. News, vol. 53, p. 447.

Suggests the above as a means of raising the water table in inclosed valleys.

631 **Stevens** (H. L.). Municipal improvements in Sorsogon, P. I.

Eng. News, vol. 531, pp. 581.

Describes measures taken by the city to protect the spring furnishing its water supply.

632 **Stone** (Ralph W.). Mineral resources of the Elders Ridge quadrangle, Pennsylvania.

Bull. U. S. Geol. Survey no. 256, 86 pp., 12 pls., 4 figs.

Gives 22 well records (Pls. X, XI, p. 57); states abundance of springs and wells (p. 79), and mentions public supply taken from wells (p. 79).

633 —— Description of Waynesburg quadrangle [Pennsylvania].

Geologic Atlas U. S., folio 121, U. S. Geol. Survey, 12 pp.

Gives deep well records (pp. 5, 11), and discusses briefly the springs, wells, and water supplies of the quadrangle.

634 —— Description of Elders Ridge quadrangle [Pennsylvania].

Geologic Atlas U. S., folio 123, U. S. Geol. Survey, 10 pp.

Describes the occurrence of springs and of the underground waters of the Mahoning and Pittsburg sandstones, and considers the sources of public supplies.

635 —— Water resources of the Elders Ridge quadrangle, Pennsylvania.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 164–165.

Describes village supplies obtained by wells in sand and gravel; notes abundance of springs, and the water-bearing nature of the Mahoning and Pittsburg sandstones.

636 —— Water resources of the Waynesburg quadrangle, Pennsylvania.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 166–167.

Describes town and village supplies obtained from shallow wells in rock and gravel, and one deep well used by a cold-storage company; mentions the comparative abundance of springs, and notes the water-bearing nature of the Upper Washington limestone and the Waynesburg sandstone.

637 **Storms** (W. H.). A noted pyrite deposit. [Deadwood, S. Dak.]

Min. and Sci. Press, vol. 91, pp. 290–291.

The mine water is strongly acid and highly impregnated with copper salts.

638 **Stose** (George W.). Water resources of the Chambersburg and Mercersburg quadrangles, Pennsylvania.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 156–158.

Describes many springs from limestone and sandstone beds furnishing water supplies for public and private use and health resorts.

639 **Stose** (George W.) and **Martin** (George C.). Water resources of the Pawpaw and Hancock quadrangles, West Virginia, Maryland, and Pennsylvania.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 58–63.

Considers briefly the underground-water conditions in the area and gives detailed description of Berkeley Springs, including their history, geologic conditions, development, uses, composition, and temperature (p. 730). The water is considered as coming from a depth of 1,000 to 1,300 feet. An analysis of the water is given.

640 **Stout** (O. V. P.). Pumping plants in Colorado, Nebraska, and Kansas.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, pp. 595–608.

Describes many wells, methods, and cost of pumping, and use of water for irrigation.

641 —— Irrigation and alkali.

The official proceedings of the Twelfth National Irrigation Congress at El Paso, Tex., November 15–18, 1904, pp. 311–317.

Discusses rise of water table due to irrigation, and consequent injury to soils in alkali regions.

642 **Strahorn** (A. T.), **Jensen** (Charles A.) and. Soil survey of the Bear River area, Utah.

Field Operations of the Bureau of Soils, 1904, U. S. Dept. Agr., pp. 995–1023, 3 maps, 1 fig.

See Jensen (Charles A.) and Strahorn (A. T.).

643 **Stretch** (R. H.). Formation of iron pyrite in gravels.

Eng. and Min. Jour., vol. 79, pp. 238–239.

Ascribes the origin of the pyrite to deposition from circulating iron-bearing waters.

644 **Student.** Ore deposits.

Eng. and Min. Jour., vol. 79, p. 335.

Discusses the agency of underground water in the formation of ore deposits.

645 **Sweet** (A. T.), **Martin** (J. O.) and. Soil survey of the Kearney area, Nebraska.

Field Operations of the Bureau of Soils, 1904, U S. Dept. Agr., pp. 859–874, 1 pl., 1 map, 1 fig.

See Martin (J. O.) and Sweet (A. T.).

646 **Swendsen** (G. L.), **Hinderlider** (M. C.), and **Chandler** (A. E.). Report of progress of stream measurements for the calendar year 1904: Part X, Colorado River and the Great Basin Drainage.

Water Sup. and Irr. Paper no. 133, U. S. Geol. Survey, 384 pp.

See Hinderlider (M. C.), Swendsen (G. L.), and Chandler (A. E.).

T.

647 **Taff** (Joseph A.). Description of the Tahlequah quadrangle [Indian Territory and Arkansas].

Geologic Atlas U. S., folio 122, U. S. Geol. Survey, 7 pp.

Notes occurrence of water in underground channels, joints, faults, etc., of Boone and Morrow formations, and describes sulphur and saline springs and a red spring deposit (p. 7).

648 **Taft** (H. H.). Notes on southern Nevada and Inyo County, California.

Bimonthly Bull. Am. Inst. Min. Eng. no 6, pp. 1279–1298.

Describes springs in the Amargosa Desert (pp. 1284–1285); deposition of silica from springs and the silicification of the country rock in the Bullfrog mining district (pp. 1287–1288); the agency of underground waters in the deposition of the ores and the silicification of the country rock in the Goldfield district (pp. 1288–1289), and the agency of underground waters in the formation of hummocks in Death Valley (p. 1294).

649 **Taft** (H. H.). Notes on southern Nevada and Inyo County, California. II.

Min. and Sci. Press, vol. 91, p. 429.

Describes some thermal mineral springs in the Amargosa Desert and discusses the agency of water in the formation of the ore deposits of the Bullfrog and Goldfield mining districts.

650 —— Notes on southern Nevada and Inyo County, California. III.

Min. and Sci. Press, vol. 91, pp. 447–448.

Describes the agency of underground water in the so-called "self-rising ground" in Death Valley.

651 **Tait** (C. E.). Pumping plants in Texas.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, pp. 341–346, 1 fig.

Describes various wells used for irrigation, and methods and cost of pumping.

652 —— Rice irrigation on the prairie land of Arkansas.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, pp. 545–565, 5 figs.

Describes experiments on use of wells in rice irrigation, giving methods of sinking and pumping wells, cost, etc.

653 **Talbot** (A. N.). Corrections necessary in accurate determinations of flow from vertical well casings.

Abstract of notes: Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 43–44, 2 figs.

Describes certain corrections which must be applied to figures in the field tables of J. E. Todd and Charles S. Slichter when refined measurements of flows from vertical well casings are desired.

654 **Tamura** (S. Tetsu). An account of recent meteorological and geo-physical researches in Japan.

Monthly Weather Review, vol. 33, pp. 302–305.

Reviews papers by Dr. K. Honda (Proc. Tokyo Physico-Mathematical Society, vol. 2, no. 6, 1903, and no. 9, 1904, and Publications of the Earthquake Investigation Committee, no. 18, 1904), explaining daily periodic changes in the level of artesian wells in Japan, and concluding that the fluctuations are due largely to tides acting on a subterranean air reservoir (pp. 303–304).

655 **Tarbell** (Arthur). Story of the Simplon tunnel.

Technical World Magazine, vol. 3, pp. 206–211, 6 figs.

Describes the hot springs encountered in the construction of the tunnel between Switzerland and Italy.

656 **Tarr** (Ralph S.). Water resources of the Watkins Glen quadrangle, New York.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 134–140.

Discusses the question of obtaining water supplies from wells sunk in the deep gravel-filled valleys. Describes the conditions revealed by wells sunk for the new supply at Ithaca, and gives sanitary analyses (pp. 136–140).

657 **Taylor** (Frank B.). Water resources of the Taconic quadrangle, New York, Massachusetts, and Vermont.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 130–133.

Describes a mineral spring, giving chemical, sanitary, and gas analyses, and considers its probable deep-seated origin in connection with a prominent fault. Mentions the relations of the Dalton artesian wells to a fault crack (pp. 132–133).

658 **Taylor** (Thomas U.). Irrigation in Texas.

Irrigation Aid, vol. 2, no. 3, p. 8.

Describes the use of water from springs and artesian wells in irrigation.

659 **Taylor** (Thomas U.). Modern rice irrigation.

The official proceedings of the Twelfth National Irrigation Congress at El Paso, Tex., November 15–18, 1904, pp. 330–336.

Describes briefly a shallow-well plant used for irrigating in Texas (pp. 334–335).

660 —— and **Hoyt** (John C.). Report of progress of stream measurements for the calendar year 1904: Part IX, Western Gulf of Mexico and Rio Grande drainages.

Water-Sup. and Irr. Paper no. 132, U. S. Geol. Survey, 132 pp.

Describes or gives discharge of Barton, Kickapoo, Lipan, Mormon, and two Santa Rosa springs, Texas (pp. 43–45, 122, 127).

661 **Teele** (R. P.). Water rights on interstate streams: The Platte River and tributaries. Results of investigation.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 157, pp. 9–95, 4 pls., 3 figs.

Discusses return seepage to the river in Colorado and Nebraska after the application of its water to land for irrigation, and gives results of experiments to determine amounts (p. 47–58, 72).

662 —— Review of the irrigation work of the year.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, 1905, pp. 19–75, 1 fig.

Discusses loss of canal water through seepage (pp. 23, 35–38); return seepage to streams from irrigated lands in Colorado, Wyoming, and Nebraska (pp. 38–50); costs, depths, and methods of pumping artesian wells used for irrigation in Texas (pp. 55–56), Arkansas (p. 57), Kansas (p. 57), and Colorado (pp. 58–59). Describes use of windmills for pumping wells (pp. 61–63). Describes experiment on use of well for irrigation in Arkansas (p. 72).

663 **Tilton** (John L.). A problem in municipal waterworks for a small city.

Proc. Iowa Acad. Sci., 1904, vol. 12, pp. 143–150.

A general discussion of the underground-water conditions in the vicinity of Indianola, Iowa, including quantity available, quality, etc.

664 **Tower** (Walter S.). The geography of American cities.

Bull. Am. Geol. Soc., vol. 37, pp. 577–588.

Mentions several mineral springs about which resorts have grown up. Hot Springs, Arkansas; Hot Springs, Virginia; Cambridge Springs, Pennsylvania, and Poland Springs, Maine, are noted.

665 **Trask** (F. E.). The irrigation system of Ontario, Cal.—Its development and cost.

Proc. Am. Soc. Civil Eng., vol. 31, pp. 264–270, pls. 29–32.

Describes the tunnels, artesian wells, and saturated gravel beds which furnish the greater portion of the water supply.

666 —— Proposed utilization of upland flood waters to increase available underground waters.

Eng. News, vol. 53, p. 42.

Suggests that the flood discharges of the canyons of southern California be diverted from place to place over porous sands and gravels.

U.

667 **Udden** (Jon Andreas). Geology of Clinton County.

Ann. Rept. Iowa Geol. Survey, 1904, vol. 15, pp. 371–431, 2 pls., 1 fig.

Gives numerous well records (pp. 382–415); mentions use of well water for Clinton, Iowa (pp. 381–385, 429), and enumerates the Niagara limestone and St. Peters sandstone as water-bearing horizons (p. 429).

668 **Ulrich** (Edward Oscar). Lead, zinc, and fluorspar deposits of western Kentucky: Part I—Geology and general relations.

Prof. Paper U. S. Geol. Survey no. 36, pp. 1–105, 7 pls.

Mentions solution of limestone by underground water (p. 19), and passage of descending water and formation of sink holes along joint planes (p. 74).

669 **U. S. Bureau of the Census.** Census of the Philippine Islands, taken under the direction of the Philippine Commission in the year 1903, 4 vols., v. 1., geography, history, and population.

619 pp., 74 pls., 7 maps, 13 figs.

Describes geologic relations, composition, and uses of mineral springs, and their distribution in lines parallel with axes of folding (pp. 192–194). Describes numerous hot springs (pp. 216–244) and solfataras (pp. 202–246).

V.

670 **Veatch** (Arthur C.). General plan and details of work [of collecting well samples].

Bull. U. S. Geol. Survey no. 264, pp. 28–39.

Describes the blanks and forms used in collecting well samples and the method of shipping them by mail in franked bags.

671 —— Louisiana and southern Arkansas.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 179–187, 3 figs.

Describes water-bearing strata in the various Tertiary, Cretaceous, and Quaternary formations. Mentions several mineral springs in Louisiana, and lists the principal publications on underground waters of the area.

672 —— The underground waters of northern Louisiana and southern Arkansas.

Bull. Louisiana Geol. Survey no. 1, pp. 82–91.

Describes the principal water-bearing horizons and geologic occurrence of artesian water in this region.

673 —— The question of origin of the natural mounds of Louisiana, Arkansas, and Texas.

Abstract: Science, new ser., vol. 21, pp. 310–311.

Discusses the spring and gas vent theory of origin.

674 **Vermeule** (C. C.). East Orange wells at White Oak Ridge, Millburn township, Essex County.

Ann. Rept. New Jersey Geol. Survey, 1904, pp. 255–263, 2 figs.

Gives distribution, yield, analysis, records, and geological section of city wells.

675 **Vernon** (J. J.). Irrigation investigations at New Mexico Experiment Station, Mesilla Park, 1904.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, pp. 303–317.

Discusses cost of irrigation with well water (pp. 311–316), and describes experiments to compare cost of irrigation by well and by river waters (pp. 308–311). Gives table of temperatures of well waters (pp. 316–317).

676 —— Development of the underflow.

Irrigation Age, vol. 20, p. 86.

Describes the results obtained by a 48-foot well put down at the Mesilla Park Agricultural Experiment Station, New Mexico.

677 —— Pumping for irrigation in New Mexico.

The official proceedings of the Twelfth National Irrigation Congress, at El Paso, Tex., November 15–18, 1904, pp. 351–355.

Mentions irrigation from pumping shallow wells in British India and deep wells in California, and states possibilities elsewhere (p. 351).

678 **Voorhees** (Edward B.). Irrigation in market-garden districts in the vicinity of eastern cities.

Bull. Office Exp. Sta., U. S. Dept. Agr., no. 148, 17 pp., 3 pls.

Describes irrigation by pumping springs on Long Island, New York (p. 10), at Belmont, Mass. (p. 13), from wells at Arlington, Mass. (p. 12), driven wells at Watertown, Mass. (p. 13), and from driven wells at Vineyard, N. J. (pp. 14, 16).

W.

679 **Walcott** (Charles Doolittle). Twenty-fifth annual report of the Director of the United States Geological Survey [1903–1904].

Twenty-fifth Ann. Rept. U. S. Geol. Survey, 388 pp.

Gives the mineral-water production for 1903 as 51,186,746 gallons, valued at $8,073,096. Describes the organization and work of the eastern and western sections of the division of hydrology, and notes work of the division of hydro-economics on the composition of underground waters. A number of underground-water investigations are also mentioned in connection with the account of the work of the Reclamation Service. The general work of the division of hydrology included investigations of the underground waters in nearly every State in the Union, those in the eastern portion being under the direction of M. L. Fuller, and those in the western under N. H. Darton. About 75 geologists were engaged in underground-water investigations during the year, the work of each being outlined in the report. In addition to the general studies the following special investigations are mentioned: Hot springs in the Yellowstone National Park, by W. H. Weed; algous growth in hot springs, by W. A. Setchell; physics of geysers, by William Hallock; relations of underground waters to the law, by D. W. Johnson, and experimental investigation and measurement of underflow, by C. S. Slichter. Lists of underground-water publications are also included.

680 —— Twenty-sixth annual report of the Director of the United States Geological Survey [1904–1905].

Twenty-sixth Ann. Rept. U. S. Geol. Survey, 322 pp.

Gives the mineral-water production for 1904 as 67,718,500 gallons, valued at $10,398,450 (p. 95). Gives the allotments for hydrologic investigations (p. 23), notes cooperative arrangements with several States (pp. 179–180), joint works with geologic branch (p. 181), and investigations for Reclamation Service (p. 202): describes in detail the work of eastern and western sections of the division of hydrology (pp. 178–210), giving lists of underground-water publications. The general work of the division of hydrology included investigations in nearly every State in the Union, those in the eastern portion being in charge of M. L. Fuller and those in the western in charge of N. H. Darton. About 75 geologists were engaged in field or office work during the year, the work of each being described in the report. In addition to the general studies, the following special work is described: Studies of thermal springs of Georgia and Yellowstone National Park, by H. H. Weed; experiments on and measurement of underground currents, by C. S. Slichter; fluctuations of wells, by A. C. Veatch; relation of underground waters to the law, by D. W. Johnson; bibliography of underground waters, collection of well records and samples, and work of division of hydro-economics on the composition of underground waters. In connection with the work of the Reclamation Service, underflow investigations in Kansas (p. 266), ground waters in Carson Valley, Nevada (p. 270), and salt spring in Oklahoma (p. 286), are described.

681 **Waller** (O. L.). Equities of the senior irrigator.

Irrigation Age, vol. 20, pp. 331–334.

Describes the excessive losses from irrigation ditches by seepage through coarse gravel subsoils in the Yakima Valley, Washington.

682 **Waring** (G. A.). The pegmatite veins of Pala, San Diego County [Calif.].

Am. Geologist, vol. 35, pp. 356–376.

Mentions mineral springs and gives composition (p. 365), and notes the alteration of pegmatite by ground waters (p. 369).

683 **Water and Forest.** Vested rights in water protected.

Water and Forest, vol. 5, no. 1, p. 6.

Discussion of the case of Newport et al. *v.* The Temescal Water Company, tried in a superior court of California. The plaintiff's contention was that the company had no right to use the underground water of the Perris Valley, because it worked to their (the plaintiff's) detriment. The evidence is reviewed. Judgment was given for the defendant company.

684 **Watson** (Thomas L.). A preliminary report on the bauxite deposits of Georgia.

Bull. Georgia Geol. Survey no. 11, 169 pp., 12 pls., 3 figs. and map.

Discusses agency of heated waters in formation of bauxite (pp. 15, 20–22, 123–125), theory of Hayes in regard to origin due to action of waters (pp. 20–22, 123–125, 129). Mentions percentage of water in composition of various minerals (pp. 37–54, 84–85), and gives probable chemical reactions (pp. 123–125, 129). Mentions water in quarries and veins (pp. 62, 66, 83, 108).

685 **Weed** (Walter Harvey). Absorption in ore deposition.

Eng. and Min. Jour., vol. 79, p. 364.

Discusses the power possessed by clays, etc., of extracting metals from mineral-bearing solutions seeping in from fissures.

686 —— Notes on the gold veins near Great Falls, Maryland.

Bull. U. S. Geol. Survey no. 260, pp. 128–131.

Notes relations of water level to the mines.

687 —— Economic value of hot-spring deposits.

Bull. U. S. Geol. Survey no. 260, pp. 598–604.

Notes the use of springs in general for bathing, heating, as source of carbon dioxide, borax, and other chemicals, and for medicinal purposes. The use of artesian wells for heating in Idaho and Montana is also mentioned. Among the spring deposits noted are tufa geyserite, cinnabar (in Nevada and California), copper (Java), tin (Malay Peninsula), stibnite, etc. (Steamboat Springs, Nevada), manganese oxide, limonite, realgar, orpiment, etc. (Yellowstone National Park), and limonite and travertine (Montana) (pp. 600–601). Describes Anaconda Hot Springs, Montana (p. 600), the gypsum veins and waters at Hunters Hot Springs, Montana (p. 601), and the use of the water in baths. The fissure origin of the springs is shown, their yield stated, and analyses given (pp. 602–604).

688 —— Notes on certain hot springs of the southern United States.

Water-Sup. and Irr. Paper no. 145, U. S. Geol. Survey, pp. 185–206.

Discusses the occurrence and geologic relations of hot springs in the United States and describes in detail the Warm Springs from the quartzites at Pine Mountain, Georgia, and the Hot Springs of Arkansas. The discussion of the latter is unusually complete and includes a consideration of the geology, topography, history, composition, tufa deposits, discharge, source of heat, permanency, etc., of the springs. Analyses of the Georgia and Arkansas waters and of the tufa deposits of the latter locality are given.

689 **Weeks** (Fred Boughton), New York.

Water-Sup. and Irr. Paper no. 114, U. S. Geol. Survey, pp. 82–92, 1 pl.

Describes underground waters in pre-Cambrian rocks, in Cambrian limestones and slates, in Ordovician limestones and slates, in Silurian sandstones and shales, in Devonian limestones, shales, and sandstones, in Triassic sandstone, and in Cretaceous beds and drift. Tabulates the production, character, and use of the mineral springs of the State. Gives bibliography.

690 **Weidman** (S.). Iron ores of Wisconsin.

Eng. and Min. Jour., vol. 79, pp. 610–612, 2 figs.

This article is an abstract from a paper which appeared in the Wisconsin Engineer, vol. 9, by Dr. S. Weidman. Discusses the occurrence of ground water in the crystalline and sedimentary rocks of the Baraboo district.

691 **West** (H. E.). Mining in Nicaragua.

Min. Magazine, vol. 11, pp. 509–514, 2 figs.

Notes the occurrence of hot water in the mines at Santa Francisca and San Luis, and suggests that the deposits are of solfataric origin.

692 **Whipple** (George C.). The water supplies of the New York Metropolitan District with special reference to their purification.

Jour. New England Waterworks Assoc., vol. 19, pp. 451–473, 12 figs.

Considerable space is devoted to the description of the underground-water resources of this region and the methods of development. The quality of the ground water, its relation to certain filter plants, etc., is also given.

693 —— [Purification of well water.]

Jour. New England Waterworks Assoc., vol. 19, pp. 549–551.

Describes the use of copper sulphate in the purification of well water in New Hampshire.

694 —— and **Levy** (E. C.). The Kennebec Valley typhoid-fever epidemic of 1902–1903. [Maine.]

Jour. New England Waterworks Assoc., vol. 19, pp. 163–214, 7 figs.

Notes the use of a spring-water supply known as the Devine water in Augusta (p. 168), and the Hallowell spring water at Togus (p. 185); discusses the relations of springs and wells to the epidemic (pp. 173–175, 176, 181, 195, 201).

695 **Whistler** (J. T.), **Ross** (D. W.), and **Noble** (T. A.). Report of progress of stream measurements for the calendar year 1904: Part XII, Columbia River and Puget Sound drainage.

Water-Sup. and Irr. Paper no. 135, U. S. Geol. Survey, 300 pp.

See Ross (D. W.), Whistler (J. T.), and Noble (T. A.).

696 **Whitby** (J. E.). Shall we all die of thirst?

Sci. Am. Supp., vol. 60, no. 1542, p. 24707.

Makes a statement that water springs and water beds are slowly drying up.

697 **Whitney** (Francis L.). The new artesian water supply at Ithaca, N. Y.

Water-Sup. and Irr. Paper no. 110, U. S. Geol. Survey, pp. 55–64, 1 pl., 1 fig.

Describes deep wells sunk in gravels, sands, and clays in the valley of Cayuga Inlet above Ithaca, and discusses the source and geologic occurrence of the supply. Gives well records and analyses.

698 **Whitney** (Milton). Report of the Chief of the Bureau of Soils.

Ann. Rept. for the year ending June 30, 1904, U. S. Dept. Agr., pp. 241–269.

Mentions irrigation by pumping artesian wells in California (p. 245), injurious effect of subirrigation in Colorado (p. 246), and irrigation by artesian wells and springs in Texas (p. 255). Summarizes injury of alkali lands through rise of seepage water due to irrigation, and work of reclamation of alkali lands by underdrainage in Utah, California, Washington, Arizona, and Montana (pp. 257–261).

699 **Wickson** (E. J.). Irrigation in fruit growing.

Irrigation Aid, vol. 2, no. 3, pp. 12–13.

Devotes one column to a discussion of the development of the underflow of streams for use in irrigation.

700 **Wiel** (Samuel C.). Water rights in California.

Min. and Sci. Press, vol. 90, pp. 6–8, 25–26.

Contains many references to cases dealing with legal questions regarding underground waters.

701 **Wilder** (F. A.). The lignite of North Dakota and its relation to irrigation.
Water-Sup. and Irr. Paper no. 117, U. S. Geol. Survey, 59 pp.
Mentions several springs giving rise to creeks (p. 31).

702 **Wile** (William H., jr.). The Escalante Desert [Utah].
Irrigation Age, vol. 21, pp. 17–20.
Notes the existence of vast quantities of alkali water underlying this desert.

703 **Wiley** (A. J.). Masonry dam for the Granite Springs reservoir, Cheyenne, Wyo.
Eng. Rec., vol. 51, pp. 698–701, 7 figs.
Contains a description of a submerged dam 6 miles above the city intersecting the underflow of Crow Creek, and of a system of infiltration galleries beneath the bed of the creek above the dam. Notes seepage through the new masonry dam erected for the storage of flood flows.

704 **Wiley** (H. W.). Experiments in the culture of sugar cane and its manufacture into table sirup.
Bull. Bureau of Chem., U. S. Dept. Agr., no. 93, 78 pp., 5 pls., 6 figs.
States production and quality of water from well at Waycross, Ga. (p. 46).

705 **Willard** (Daniel E.), **Hall** (Charles M.) and. Description of Casselton and Fargo quadrangles [North Dakota and Minnesota].
Geologic Atlas U. S., folio 117, U. S. Geol. Survey, 7 pp.
See Hall (Charles M.) and Willard (Daniel E.).

706 **Williams** (Ira A.). Geology of Jasper County.
Ann. Rept. Iowa Geol. Survey, 1904, vol. 15, pp. 279–367, 12 figs., 2 maps.
Estimates proportion of rainfall absorbed by rock and soil (p. 295); gives well records (pp. 306–363); discusses distribution of springs and flowing wells (pp. 360–363); gives chemical and sanitary analyses of water from gravel (p. 362) and from St. Louis and Maquoketa beds (p. 361); describes various mineral waters, some carbonated; gives analysis of calcic-saline-chalybeate water (pp. 363–365); and summarizes therapeutic value of mineral waters in general (pp. 365–366).

707 **Willis** (Bailey). Geological researches in eastern Asia.
Yearbook Carnegie Institution of Washington, no. 3, 1904, pp. 275–291.
Mentions an artesian-water investigation made by him at Peking, and suggests possibility of supplying the city from this source (p. 290).

708 **Wilson** (James). Report of the Secretary of Agriculture 1905, 132 pp.
Summarizes work of reclaiming alkali lands by underdrainage in Utah, Montana, Washington, and California (pp. 79–80).

709 —— Report of the Secretary.
Yearbook U. S. Dept. Agr., 1904, pp. 9–118.
Mentions storage of water by forests (p. lvi). Describes work of reclaiming alkali lands by underdrainage, and injurious effect of irrigation through raising the ground-water level and water-logging wide areas (pp. lxxii–lxxiv). Describes irrigation by pumping and mentions kinds of pumps (p. cvii).

710 **Winchell** (N. H.). Deep wells as a source of water supply for Minneapolis.
Am. Geologist, vol. 35, pp. 266–291.
Discusses artesian conditions in the drift and rock basins and gives maps of basins and wells. The St. Peter sandstone, Shakopee fissured limestone, and New Richmond, Jordan, and Hinckley sandstones constitute the water horizons, all but the last two yielding good water. The rate and cost of drilling, capacity of wells, composition of water, and supplies of St. Paul and Winnipeg are also considered. States that term "artesian" is used locally for any deep well, but recommends restricting it to flows.

711 **Winchell** (N. H.). The Willamette meteorite.
Am. Geologist, vol. 36, pp. 250–257.
In a footnote the author mentions the occurrence of corroded limestone, which he ascribes to the action of sublacustrine springs, in Thunder Bay, Lake Huron, Michigan (p. 255).

712 **Winslow** (C. E. A.). A winter visit to some sewage-disposal plants in Ohio, Wisconsin, and Illinois.
Jour. Assoc. Eng. Soc., vol. 34, pp. 335–361, 10 figs.
In the discussion accompanying this article, Mr. X. H. Goodnough notes the increased leakage of ground water into sewers in the early spring (pp. 352–353).

713 **Witt** (Otto N.). The origin of coal and of carbonated spring waters.
Sci. Am. Supp., vol. 60, p. 24791.
Discusses the theory that water and carbon dioxide of certain springs is due to the internal combustion of buried organic matter.

714 **Wittmann** (Ernest). The geological and topographical features of the city of Monterey, Nuevo Leon, Mexico, and its vicinity.
Am. Geologist, vol. 35, pp. 171–179.
Notes the occurrence and movement of water in gravels, the motion being sometimes visible in shallow wells (p. 174). Mentions a 2,100-foot well which failed to get water. Describes rise of hot sulphur water along fissure from an estimated depth of 3,000 feet, the rise being ascribed to "pressure exercised by the expansion of the heated water itself" (p. 176).

715 **Wood** (B. D.), **Hoyt** (John C.) and. Index to the hydrographic progress reports of the United States Geological Survey, 1888–1903.
Water-Sup. and Irr. Paper no. 119, U. S. Geol. Survey, 253 pp.
See Hoyt (John C.) and Wood (B. D.).

716 **Woodbridge** (Dwight E.). The Mesabi iron-ore range. (X.) [Minnesota.]
Eng. and Min. Jour., vol. 79, pp. 698–700, 2 figs.
This part (the tenth) contains a discussion of the agency of underground waters in the formation of the deposits.

717 **Woodman** (Alpheus G.), **Richards** (Ellen H.) and. Air, water, and food from a sanitary standpoint.
New York and London, 1904, 262 pp., 13 figs., 1 map.
See Richards (Ellen H.) and Woodman (Alpheus G.).

718 **Woodward** (S. M.). Cost of pumping for irrigation.
Bull. Univ. of Ariz. Agric. Exp. Sta. no. 49, pp. 457–469.
Describes pumping plants at several dug and drilled wells, and gives results of investigations regarding cost.

719 **Wright** (A. E.) and **Collins** (A. B.). Irrigation near Garden, Kans., 1904.
Bull. Office Exp. Sta., U. S. Dept. Agr., no. 158, pp. 585–594.
Describes methods of obtaining irrigating waters by means of wells into the "underflow," and describes methods of pumping by windmills.

720 **Wright** (Fred Eugene). Report of progress in the Porcupines.
Ann. Rept. Michigan Geol. Survey, 1903, pp. 33–44.
Describes occurrence of springs in connection with faulting (pp. 39, 40); mentions disappearance of streams below ground (p. 41), and their origin in mountain springs (p. 43).

Y.

721 **Yale** (Charles G.). Borax.
Mineral Resources U. S. for 1904, U. S. Geol. Survey, pp. 1017–1028.
Notes the location of an artesian well near Borax Lake, Lake County, Cal. The artesian water so diluted the waters of the lake that the manufacture of borax from the lake water became unprofitable (p. 1017).

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CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 163.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

Most of the above publications may be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they may be had at prices slightly above cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they may be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the fifty-ninth in Series O, the complete list of which follows (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

SERIES O, UNDERGROUND WATERS.

WS 4. A reconnaissance in southeastern Washington, by I. C. Russell. 1897. 96 pp., 7 pls. (Out of stock.)

WS 6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls. (Out of stock.)

WS 7. Seepage waters of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls. (Out of stock.)

WS 12. Underground waters of southeastern Nebraska, by N. H. Darton. 1898. 56 pp., 21 pls. (Out of stock.)

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WS 31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., 4 pls. (Out of stock.)

WS 34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 19 pls.

WS 53. Geology and water resources of Nez Perces County, Idaho, Pt. I, by I. C. Russell. 1901. 86 pp., 10 pls. (Out of stock.)

WS 54. Geology and water resources of Nez Perces County, Idaho, Pt. II, by I. C. Russell. 1901. 87-141 pp. (Out of stock.)

WS 55. Geology and water resources of a portion of Yakima County, Wash., by G. O. Smith. 1901 68 pp., 7 pls. (Out of stock.)
WS 57. Preliminary list of deep borings in the United States, Pt. I, by N. H. Darton. 1902. 60 pp. (Out of stock.)
WS 59. Development and application of water in southern California, Pt. I, by J. B. Lippincott. 1902. 95 pp., 11 pls. (Out of stock.)
WS 60. Development and application of water in southern California, Pt. II, by J. B. Lippincott. 1902. 96–140 pp. (Out of stack.)
WS 61. Preliminary list of deep borings in the United States, Pt. II, by N. H. Darton. 1902. 67 pp. (Out of stock.)
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WS 90. Geology and water resources of a part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.
WS 101. Underground waters of southern Louisiana, by G. D. Harris, with discussions of their uses for water supplies and for rice irrigation, by M. L. Fuller. 1904. 98 pp., 11 pls.
WS 102. Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller. 1904. 522 pp.
WS 104. Underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls.
WS 110. Contributions to the hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge. 1904. 211 pp., 5 pls.
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WS 114. Underground waters of eastern United States; M. L. Fuller, geologist in charge. 1904. 285 pp., 18 pls.
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B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.
WS 120. Bibliographic review and index of papers relating to underground waters, published by the United States Geological Survey, 1879–1904, by M. L. Fuller. 1905. 128 pp.
WS 122. Relation of the law to underground waters, by D. W. Johnson. 1905. 55 pp.
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WS 136. Underground waters of the Salt River Valley, by W. T. Lee. 1905. 194 pp., 24 pls.
B 264. Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch. 1905. 106 pp.
PP 44. Underground water resources of Long Island, New York, by A. C. Veatch and others. 1906. 394 pp., 34 pls.
WS 137. Development of underground waters in the eastern coastal plain region of southern California, by W. C. Mendenhall. 1905. 140 pp., 7 pls.
WS 138. Development of underground waters in the central coastal plain region of southern California, by W. C. Mendenhall. 1905. 162 pp., 5 pls.
WS 139. Development of underground waters in the western coastal plain region of southern California, by W. C. Mendenhall. 1905. 105 pp., 7 pls.
WS 140. Field measurements of the rate of movement of underground waters, by C. S. Slichter. 1906. 122 pp., 15 pls.
WS 141. Observations on the ground waters of Rio Grande Valley, by C. S. Slichter. 1905. 83 pp., 5 pls.
WS 142. Hydrology of San Bernardino Valley, California, by W. C. Mendenhall. 1905. 124 pp., 13 pls.
WS 145. Contributions to the hydrology of eastern United States; M. L. Fuller, geologist in charge. 1905. 220 pp., 6 pls.
WS 148. Geology and water resources of Oklahoma, by C. N. Gould. 1905. 178 pp., 22 pls.
WS 149. Preliminary list of deep borings in the United States, second edition, with additions, by N. H. Darton. 1905. 175 pp.
PP 46. Geology and underground water resources of northern Louisiana and southern Arkansas, by A. C. Veatch. 1906.
WS 153. The underflow in Arkansas Valley in western Kansas, by C. S. Slichter. 1906.

WS 154. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 64 pp., 15 pls.

WS 155. Fluctuations of the water level in wells, with special reference to Long Island, New York, by A. C. Veatch. 1906.

WS 157. Underground water in the valleys of Utah Lake and Jordan River, Utah, by G. B. Richardson.

WS 158. Preliminary report on the geology and underground waters of the Roswell artesian area, New Mexico, by C. A. Fisher. 1906. 29 pp., 9 pls.

PP 52. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906.

WS 159. Summary of the underground water resources of Mississippi, by A. F. Crider and L. C. Johnson. 1906.

PP 53. Geology and water resources of the Bighorn Basin, Wyoming, by C. A. Fisher. 1906.

WS 160. Underground-water papers, 1906, by M. L. Fuller. 1906.

WS 163. Bibliographic review and index of underground-water literature published in the United States in 1905, by M. L. Fuller, F. G. Clapp, and B. L. Johnson. 1906. 130 pp.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian-well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

UNDERGROUND WATERS

OF

TENNESSEE AND KENTUCKY WEST OF TENNESSEE RIVER

AND OF

AN ADJACENT AREA IN ILLINOIS

BY

L. C. GLENN

WASHINGTON

GOVERNMENT PRINTING OFFICE

1906

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ILLUSTRATIONS.

UNDERGROUND WATERS OF TENNESSEE AND KENTUCKY WEST OF TENNESSEE RIVER AND OF AN ADJACENT AREA IN ILLINOIS.

By L. C. GLENN.

INTRODUCTION.

In this report is described an area in western Tennessee and Kentucky and southern Illinois in which the surface formations are for the most part unconsolidated deposits that were laid down in an embayment of the great sea that once existed in the Mississippi Valley. In Tennessee this embayment area includes the portion of the State between Mississippi and Tennessee rivers with the exception of a narrow strip along the west bank of Tennessee River. In Kentucky it includes all of the State west of Tennessee River with the exception of a narrow strip that extends along the west bank almost to Paducah. In Illinois it includes a large part of Massac, Pulaski, and Alexander counties.

A part of the summer of 1903 was spent in field work, and since that time several trips have been made across various portions of the area. Much information has been obtained by correspondence with owners of wells and springs and with well drillers. The Illinois portion of the area did not receive as much study as the others, but the data obtained are of sufficient value to warrant their inclusion.

SOURCE OF UNDERGROUND WATER.

With the exception of deep underground supplies from porous beds that have received their water where they rise to the surface, perhaps many miles distant, the water supply of any region is abundant or deficient, constant or variable, in accordance with the character of the rainfall. Only a part of the rainfall contributes to the underground water supply. The total precipitation may be divided most conveniently into three portions. One portion runs down the surface slopes and flows into the streams and to the sea. A second portion is absorbed by the soil and fills the pores and cracks in the solid rocks and the interstices in the loose sands and clays, and thus saturates all the strata that are at no great depth beneath the surface. The upper limit of this saturation, or the water table, is not a plane, but a modified reproduction of the actual surface. It rises beneath hills, though

not so steeply as the hills, and sinks beneath valleys, though often so much less abruptly that it intersects the valley slope. Where the water table does not lie too far beneath the surface it may be reached by digging wells. Where it intersects the surface it produces springs or marshes. From these springs a part of the absorbed portion of the rainfall flows to the streams in the same manner as the portion that runs off directly during and for a short time after rains, and except this amount furnished by direct run-off, the supply from springs is the sole dependence of the surface streams. A third portion of the rainfall is temporarily absorbed by the earth or held by the covering of leaves and vegetation to be evaporated again by the sun either directly or by transpiration through plant growth.

The water resources of the region discussed in this paper are very largely dependent on its rainfall. The springs and shallow wells derive their supplies exclusively from the rain falling in their immediate vicinity, while the strata from which the deep wells obtain water, though in many cases not reached by the immediately local rainfall, are supplied by rain that falls within the limits of the region or in the region just west of Mississippi River in which Gulf embayment deposits also occur. In only a very few cases do deep wells pierce the hard rocks that lie beneath the soft sands and clays of the embayment deposits and derive their water from rain which has fallen where these hard rocks outcrop, beyond the Gulf embayment area.

ARTESIAN CONDITIONS.

GENERAL STATEMENT.

The requisite conditions for the occurrence of artesian wells in any region are few, simple, and easily understood. It is often difficult, however, to ascertain whether a given region meets all the necessary conditions. In applying the principles of artesian-well occurrence to particular localities numerous subsidiary problems may arise that may greatly modify results and much uncertainty may exist as to the exact geologic conditions present. The requisite conditions have been formulated by T. C. Chamberlin [a] as follows:

1. A pervious stratum to permit the entrance and the passage of the water.
2. A water-tight bed below to prevent the escape of the water downward.
3. A like impervious bed above to prevent escape upward, for the water, being under pressure from the fountain head, would otherwise find relief in that direction.
4. An inclination of these beds, so that the edge at which the waters enter will be higher than the surface at the well.
5. A suitable exposure of the edge of the porous stratum, so that it may take in a sufficient supply of water.
6. An adequate rainfall to furnish this supply.
7. An absence of any escape for the water at a lower level than the surface at the well.

[a] Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 134-135.

WATER-BEARING BEDS.

In close-grained strata like limestones water is found in cracks, fissures, and irregular cavities; in open-grained rocks like sandstones, sands, and gravels it occurs in the pores and interstices between the rock particles. In the region under consideration all the rocks through which waters freely pass are open-grained sands and gravels. The size of the rock particles varies greatly, however, ranging from

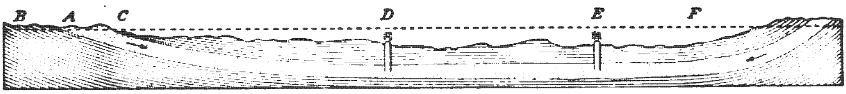


Fig. 1.—Section showing principal requisites of artesian wells. *A*, a porous stratum; *B*, *C*, impervious beds below and above *A*, acting as confining strata; *F*, height of water level in porous bed : *A*, or, in other words, height in reservoir or fountain head; *D*, *E*, flowing wells springing from the porous water-filled bed *A*.

fine silty sands, through which water flows slowly and with difficulty, tò very coarse sands, fine gravels, or even cobbles in exceptional cases, which yield their water supplies freely. The loose, porous water-bearing beds of the region are the Lagrange sands, the Ripley sands, and the Eutaw sands, each of which is described in detail. The areal occurrence of each is shown by the geologic map (Pl. I).

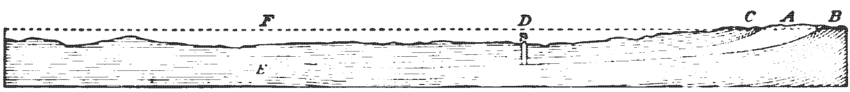


Fig. 2.—Section illustrating thinning out of porous water-bearing bed *A*, inclosed between impervious beds *B*, *C*, thus furnishing conditions for artesian well at *D*, but not at *E*.

As the dips are westward each formation occurs as an underground bed in all of the area west of its outcrop.

Immediately underlying the entire area is a floor of hard, close-grained rocks which in some places are sufficiently seamed and fissured to furnish a supply of artesian water. The drill has pierced these hard beds underlying the loose embayment deposits in only a

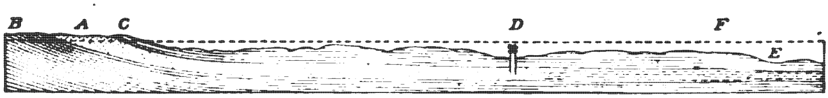


Fig. 3.—Section showing transition from porous to impervious bed. As the bed *A* is inclosed between impervious beds *B* and *C*, an artesian well is obtained at *D*. At *E*, however, *A* is impervious and water can not be obtained.

few places around the edges of the area, where the old rock floor is not deeply covered by the later deposits, as at Corinth, Miss.; Lexington, Tenn.; Paducah and Wickliffe, Ky.; Cairo, Ill.; and Morehouse, Mo. At some of these places the underlying hard beds are fissured and yield water; at others they are without notable fissures and yield little or none.

CONFINING BEDS.

Both above and below the water-bearing bed there must be beds of impervious material that prevent the escape of the water by natural means. The imprisoned water thus accumulates under pressure until the impervious cover is pierced by the drill.

The presence of an impervious bed directly beneath the porous water-bearing stratum is not so important as that of one over it, since, if the underlying bed does permit the passage of water through it, the escape is downward and lower impervious beds are almost sure to be reached in a short distance, so that usually the ultimate escape of the water is prevented.

In the region under discussion the lowest water-bearing bed of the embayment deposits over a considerable though as yet not accurately delimited portion of the area is the Eutaw sand. Beneath it are cherts, limestones, shales, or sandstones of Paleozoic age that at some places are impervious. At other places they are seamed or fissured, but the water received from overlying beds does not escape either along the seams or downward, as is shown by the great rise of the water in wells that enter these fissured beds.

The fine close-grained clays of the Selma clay form an impervious cover above the Eutaw sand and an impervious floor for the overlying Ripley sands. The Porters Creek clays form both an impervious cover for the Ripley sands beneath them and an impervious floor for the pervious Lagrange sands above them.

DIP.

The dip of the Paleozoic floor upon which the embayment sands and clays rest is westward in Tennessee; but to the north, toward the head of the embayment, the dip gradually changes to southwestward in Kentucky, and finally becomes southward in southern Illinois, at the northern margin of the deposits. Farther west, across southeastern Missouri and eastern Arkansas, it is southeastward. The rock floor in the northern part of the embayment is consequently spoon-shaped, with the tip of the spoon extending northward into southern Illinois and its eastern half underlying western Tennessee and Kentucky.

While not much is known of the structure of this Paleozoic floor, because few borings have penetrated it, a study of the borings and of the beveled surface in visible contact with the embayment deposits around their margin indicates that the shape of the floor is not the result of downward folding of one stratum or series of strata, but is due, at least mainly, to erosion which occurred while the Paleozoic rocks formed the actual surface of the region, before the embayment

deposits had been laid down. The sands and clays of the northern half of the embayment were deposited in successive strata upon this rock floor. They accordingly dip westward in Tennessee, westward and southwestward in Kentucky, and southward in Illinois, in conformity with the dips of the underlying Paleozoic surface.

The rocks dip somewhat more steeply near their outcropping edges than they do farther out in the embayment area. The dip of the Selma clay from its eastern edge near Tennessee River westward to Selmer, Tenn., is about 25 feet per mile. The westward dip of the Lagrange beds from their eastern edge east of Saulsbury, on the Southern Railway, to Memphis is about 22 feet per mile. The southwestern dip of the Paleozoic floor from Paducah to Hickman, Ky., is about 27 feet per mile, and its southern dip from a point near Ullin to Cairo, Ill., is about 27 feet per mile.

EXPOSURE OF POROUS STRATA.

The porous strata that may furnish artesian water are the Eutaw sand, the Ripley sand, and the Lagrange sand. The Eutaw sand lies immediately on the Paleozoic floor and outcrops along the eastern edge of the area discussed in a belt that varies from less than a mile to about 8 miles in width and extends northward from the Mississippi line about halfway across the State of Tennessee.

The Ripley sands outcrop in a belt that varies from 5 to 15 miles in width. This belt is situated some distance west of and parallel to the outcrop of the Eutaw sand as far north as the Eutaw and the intervening Selma clay extend as surface formations. About halfway across the State of Tennessee the two older formations disappear, and thence northward across western Kentucky and into southern Illinois the Ripley sands rest on the underlying Paleozoic rocks, and consequently outcrop in a belt immediately west of them. In Kentucky this belt averages about 6 miles in width, but it narrows considerably near Paducah before passing into Illinois. In Illinois exposures are poor and rare, so that the width of the Ripley outcrop is difficult to determine, but it would seem to be as great as the average in Kentucky.

Though the Eutaw and Ripley formations outcrop in narrow belts, these belts are wide enough to absorb many times as much water as will be required to supply any prospective demand.

The Lagrange sand forms the surface of more than half the entire area under consideration, so that there can be no question as to the sufficiency of the supply of water absorbed by it. This formation, however, does not conform strictly to the conditions of a porous artesian stratum, as do the two lower formations, the Ripley and

Eutaw, since, except locally in the western part of the area, as at Memphis, it is not overlain by an impervious bed to prevent the upward escape of the water, but forms the surface of the country in the area of its occurrence save for the thin and, as confining beds, unimportant deposits of Lafayette gravel and Columbia loess and loam.

RAINFALL.

As the supply of underground water is dependent on the rainfall, the amount and distribution of the latter is very important. The following table has been prepared from the records of the United

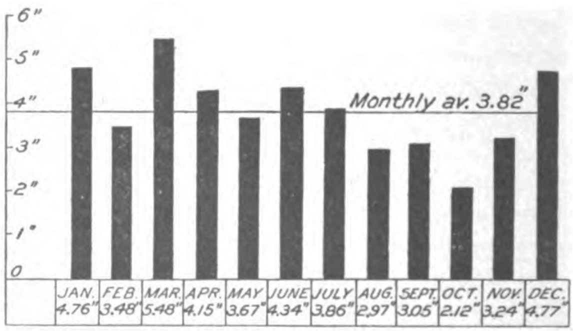


FIG. 4.—Diagram showing graphically the monthly average rainfall in the area discussed.

States Weather Bureau to show the average monthly rainfall at a number of places in and near the area here discussed. The monthly averages are shown graphically in fig. 4.

Monthly rainfall, in inches, at Weather Bureau stations in the embayment area.

Station.	Length of record (years).	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Illinois:													
Cairo	34	3.82	3.89	3.79	3.82	3.78	4.42	4.97	2.83	2.54	2.70	4.10	3.32
Kentucky:													
Blandville	11	4.56	3.12	5.44	3.49	3.70	4.77	4.19	1.82	3.23	2.52	3.22	4.12
Mayfield	......	4.17	2.09	6.48	2.34	2.86	3.83	6.93	3.00	2.89	.84	.57	4.19
Paducah	13	4.08	3.50	4.93	3.92	3.67	5.18	3.94	2.75	3.20	2.32	3.75	3.68
Missouri:													
Caruthersville	5-6	3.99	4.07	5.65	3.20	4.23	4.80	3.60	2.67	3.72	1.53	Trace	4.52
Tennessee:													
Arlington	14-23	......	......	......	3.65	3.83	4.36	3.90	3.24	2.45	2.02	......	......
Bolivar	18-21	5.38	3.78	5.40	5.09	3.58	4.01	3.74	2.39	3.13	2.24	3.76	4.31
Brownsville	21-23	......	.98	6.68	4.33	3.46	4.49	3.52	2.83	2.66	2.21	4.39	......
Covington	17-23	5.08	4.35	5.83	4.34	3.93	4.26	3.37	3.10	2.63	1.87	4.13	4.91
Dyersburg	8-23	......	3.90	4.87	5.24	3.66	4.08	3.60	2.95	3.09	2.28	4.55	3.89
Jackson	13	4.52	3.01	4.80	4.91	3.78	4.36	4.60	2.53	2.26	2.15	3.93	5.12
Kenton	4	4.72	2.53	5.06	4.03	2.32	2.74	3.10	2.15	2.92	.94	.70	7.43
McKenzie	16	......	......	......	......	......	......	......	......	......	......	4.06	......
Memphis	35	5.46	5.20	5.86	5.47	4.53	4.66	3.54	3.57	3.05	2.72	4.58	4.35
Milan	18-23	......	......	......	4.51	4.09	4.58	3.74	3.93	3.16	2.21	......	......
Savannah	19-22	4.85	4.98	5.78	4.44	4.10	4.94	4.17	3.60	3.83	2.22	3.77	4.93
Springville	......	3.99	1.92	6.30	3.22	2.55	2.67	1.66	1.60	4.08	......	1.33	7.19
Trenton	21	5.79	4.60	5.50	4.41	3.68	4.41	3.45	3.26	3.09	2.70	4.51	4.34
Wildersville	9	6.26	3.69	5.30	4.21	4.31	5.62	3.45	5.18	......	2.68	3.75	5.22
Average	......	4.76	3.48	5.48	4.15	3.67	4.34	3.86	2.97	3.05	2.12	3.24	4.77

Monthly average, 3.82 inches; yearly average, 45.89 inches.

The average annual rainfall varies from a minimum of about 43 inches yearly, as at Center Point, Tenn., and Cairo, Ill., to a maximum of about 52 or 53 inches, as at Savannah and Memphis, Tenn. The general average for the entire region is between 47 and 48 inches.

The monthly distribution is not uniform throughout the year. While the monthly average for the year is 3.92 inches, from July to October it is only 2.17 inches, and from November to March it is 5.90 inches. The driest part of the year is the late summer and fall; the wettest is the winter, especially the latter part of it. Streams and ponds are in consequence lowest in the late fall and in some cases become entirely dry. They are highest in late winter and very early spring. In many cases shallow wells are also affected almost as directly as the ponds and streams. During the long, dry fall the water may get low or fail altogether, while during winter and spring the supply is most abundant, and in some wells the water rises to the surface.

Deep wells receiving their supply from surface sources which may be many miles distant are not measurably affected by the seasonal variations in rainfall, and furnish an almost unvarying supply. Springs may, like deep wells, be unaffected by variations in the rainfall, or the ground-water level from which they derive their supply may be so near the surface that when it is lowered during prolonged dry weather the flow of the springs naturally diminishes or even entirely ceases.

ABSENCE OF LOWER ESCAPE.

Eutaw and Ripley formations.—For water to rise and flow from a deep well there must be no means of escape at a lower level. The Eutaw and Ripley formations are not known to outcrop except along their elevated edges on or near the margin of the embayment deposits. To the south, toward the Gulf of Mexico, along the deepest portion of the erosion trough in which they are deposited, the dip carries them farther from the surface; but it is highly probable that they either pass into finer grained impervious beds or are overlapped and sealed up by other fine-grained strata, so that there is no free escape southward of the waters that enter their exposed edges along the belt of outcrop. The waters thus imprisoned fill the pore space in the beds up to the level of the ground water in the area of their outcrop, and so exert a pressure on all lower parts of the beds that forces the water in deep wells up nearly to the outcrop level. The amount by which the water in a well falls short of this level depends on the friction or resistance to the flow through the water-bearing bed, which is determined by the distance the water flows from its point of entrance into the bed and by the coarseness or fineness of the materials of which the bed is composed.

Lagrange formation.—The Lagrange either outcrops over much of the region or is covered by only a few feet of Lafayatte or Columbia deposits. Its contained waters consequently escape wherever the ordinary ground-water level intersects the surface, and they rise in deep bore holes to about the level of the ground water. The formation contains beds of close-grained sands and impermeable clays that may extend over considerable areas and confine the waters beneath under such pressure that they may rise, when these beds are pierced by the drill, to a level somewhat lower or higher than that of the local ground water, owing to the local lack of free vertical communication and circulation and to the more intimate connection of the lower coarser beds with some distant part of the formation whose elevation determines the pressure at the boring. Hence a partial escape only is found for the contained waters of the Lagrange. Under certain conditions wells sunk to porous strata in this formation may flow with slight heads. No great surface pressure is obtainable anywhere in it, or indeed in any of the other water-bearing formations in the area under consideration, since the difference in level between the distant source and the surface exit at the well mouth can not anywhere be great, because there are no great differences in surface elevation in the general region. The relation of these various beds to artesian conditions is shown in fig. 7.

PHYSICAL FEATURES OF REGION.

EMBAYMENT AREA IN TENNESSEE AND KENTUCKY.

TOPOGRAPHIC TYPES.

General character.—The surface of the part of Tennessee and Kentucky under discussion varies from a very flat flood plain along the main rivers and their principal tributaries to a gently rolling or hilly surface along the sides of the valleys and in the interstream areas. Occasionally the interstream areas are level and plateau-like and are fringed with hills that have been carved by the tributaries of the adjacent streams. Generally the surface is rolling or moderately hilly and is cut into bolder hills near the valleys of the larger streams. These valleys vary from a fraction of a mile to several miles in width, and a large part of each is the present-day flood plain. In most of the valleys there are also considerable portions of an older, higher flood plain which is from 2 to 20 feet or more above the present flood plain, and which, especially along the larger tributaries of Mississippi River in Tennessee, is several miles in width. This old flood plain is commonly known as the "second bottoms," and is generally separated from the present flood plain by a steep, well-marked scarp.

The types of surface described below have in their respective areas

an influence on the local problems relating to water resources, the nature of which is set forth in some detail on later pages of this report.

Hills of erosion.—An unusually hilly belt in the eastern part of the Lagrange area extends across Tennessee and Kentucky, though it is most prominently developed in Hardeman and Henry counties, Tenn. The materials are soft sands with lenses of clay that are easily eroded. Gullies and ravines form rapidly in abandoned fields. These ravines average not over 20 or 30 feet in depth, but under especially favorable conditions they may become 100 feet deep or over.

Residual ridge.—A ridge half a mile wide and between 100 and 150 feet high extends northward from Mississippi into the southwestern part of McNairy County, Tenn., but gradually dies out to the north in this county. It is composed of Ripley sands and clays and owes its existence to the large amount of concretionary ironstone into which its sands have been cemented in many places and which has protected it from erosion while the areas on either side have worn away. This ridge is crossed by the Southern Railway in what is known as the "big cut" just west of Cypress station.

East of the ridge the Eutaw sands and clays that outcrop along the eastern edge of the embayment in the southern half of Tennessee are in many places cut into steep hills, both because of the nature of their materials and because of their situation on the short, steep drainage slope of Tennessee River.

Flatwoods.—The surface of parts of the belt underlain by the Porters Creek clays, in both Tennessee and Kentucky near the line between the two States, is of more than average flatness. In Mississippi this formation has so marked a tendency to produce flat topography that it is there known as the Flatwoods clay and the surface underlain by it as the flatwoods. Aside from the area mentioned above, its surface in Tennessee and Kentucky is not notably flat. In Illinois it is not known to form any portion of the actual surface, being there overlain and concealed, except along the Ohio River bluff at Caledonia, by Lafayette gravels and the loess.

Tennessee-Mississippi divide.—The most elevated part of western Tennessee is found in eastern McNairy County in a narrow belt extending north and south and forming the divide between the Mississippi and the Tennessee drainage. This divide has been called by Safford the Tennessee Ridge. It averages from 450 to 500 feet in height, though in places it reaches an altitude of about 600 feet above sea level. It extends northward parallel to Tennessee River and from 10 to 25 miles west of it. As this ridge is near Tennessee River it divides western Tennessee and western Kentucky into two drainage slopes of very unequal size. The one to the east, tributary to Tennessee River, is steep and narrow, and streams that flow directly into the Tennessee are short. In the northern half of the belt, how-

ever, the main tributaries, such as the Big Sandy in Tennessee and Blood and Clarks rivers in Kentucky, instead of entering the Tennessee direct, flow parallel to it, and hence are much longer than would be expected from the width of the slope. West of Tennessee Ridge the general surface slope to the Mississippi is much longer and gentler. The main streams, such as Wolf, Loosahatchie, Hatchee, and Obion rivers in Tennessee and Bayou de Chien, Obion Creek, and Mayfield Creek in Kentucky, flow more directly into the Mississippi, though Mayfield Creek makes a notable bend so that its upper part parallels the Mississippi, but flows in the opposite direction. The fall per mile in all these streams tributary to the Mississippi is small, and they do not as a rule furnish opportunities for developing water power. In places, indeed, their flood plains are undrained cypress swamps.

From Tennessee Ridge eastward the surface slopes gently, but along the edge of the Tennessee Valley there is a rather abrupt drop of 150 to 250 feet to the river flood plain. Westward from the divide the general surface slope is toward the Mississippi; but this statement is true in only a very broad sense. Everywhere the appreciable slope is toward the main drainage ways. As stated in the preceding paragraph, a high narrow ridge extends northward from Mississippi some distance into Tennessee along the outcrop of the Ripley sands and interrupts locally the general westward slope. Another higher belt that extends northward from the region of Grand Junction, past Jackson toward Milan, reaches elevations of over 500 feet on the divides between the streams that flow westward across it. This interruption in the general westward slope is not a single ridge, but rather a belt a number of miles in width. It coincides with the eastern part of the outcrop of the soft Lagrange sands with their interbedded clay lenses that give in detail the hilly topography already described.

Alluvial region.—West of the line of bluffs which terminates the uplands of western Tennessee and Kentucky, along Mississippi and Ohio rivers, there is a variable width of alluvial bottom lands, which belong to the flood plains of these streams, though under present conditions portions of them rise as low ridges or swells high enough not to be submerged during floods. The surface of these bottoms is either flat, broken by low ridges a few feet high, or intersected by narrow sloughs and partly filled channels in which water is found. It is somewhat higher near the river bank and this part is largely cleared and cultivated. Back from the river, near the bluffs, the surface is lower and much of it is swampy and uncleared. The slope of the surface is about the same as that of the high-water level of the Mississippi. This has an elevation at Cairo of about 320 feet and at the Mississippi State line of about 215 feet. Above Cairo the Ohio flood plain is well developed and wider on the Kentucky side of the river and has

much the same characteristics as the Mississippi flood plain just described. Its elevation at Paducah is about 340 feet and at Cairo about 320 feet.

ORIGIN OF THE TOPOGRAPHY.

Except in the area adjacent to Reelfoot Lake, in the northwest corner of Tennessee, where there were surface disturbances during the New Madrid earthquake of 1812, all surface inequalities found in the region are due to erosion. The surface was originally a plain of marine deposition formed beneath the waters of the Gulf when it extended into southern Illinois. If several minor episodes of uplift and depression—probably with tilting or warping—are disregarded it may be said that this Gulf bottom was subsequently uplifted and has since been thoroughly but not deeply dissected by the streams that have established themselves on every part of it.

Stream activities.—Because the elevation was not great, erosion has not been profound. The streams soon cut as deeply into the surface as they could and then began widening their valleys. Since the materials are mostly soft sands and clays, valley widening and flood-plain formation have been relatively rapid. Flood plains on streams like the Wolf, the Forked Deer, and the Obion had grown in places from 3 to 5 miles or more wide when a further slight uplift caused the streams to incise themselves from a few feet to 20 feet beneath this level and begin the cutting away of the old flood plain, now called the second botoms, and the building of a new one which has attained a width of from a few hundred yards to a mile or more. Between the formation of the broad ancient flood plain and the uplift, which permitted the cutting of the present flood plain, there was a brief and slight depression during which the old plain was sheeted with a deposit of loess.

As a rule the hills carved from the old surface by stream erosion are higher, but of gentler slope near the main drainage ways, because they have been weathering away there longest; they are lower but of steeper slope along the upper waters of the tributaries, because there they have been most recently cut.

Nature of erosion in sandy and clayey strata.—While strata of soft sands are easily eroded into steep-sided hills separated by narrow gullies or ravines, the tops of these hills do not waste away with equal ease but remain at almost their original altitude. In a climate such as that of the region under discussion, two parallel outcrops of sands and clays, at the same original elevation, will erode very differently. The clays are apt to retain a reasonably flat surface which is slowly lowered by erosion, as, for instance, in the belt of Porter's Creek or "Flatwoods" clays immediately east of the Lagrange sands. Nearly all of the rain falling on the clay area must run off in surface streams.

Down any steep slopes that tend to develop by stream cutting the rain wash would be great and such quantities of material would be furnished to the streams as would not only prevent their cutting deep channels but tend to make them build flat flood plains. Time would witness only a gradual lowering of the general surface, whose gentle slopes would maintain the equilibrium between rain wash and stream transportation.

The sand area will be cut into hills, but the general level of the hill-tops will remain almost unchanged. All of the rain falling on the surface would be directly absorbed as if by a blotter and streams would not be formed until the ground-water level rose to the surface in some low place. The stream thus originating would at once begin eroding the soft sands along its way. Since even during rains such a stream would be fed by percolation through the sands rather than by run-off from the surface, it would be left free to deepen its channel and carve the surface into hills, whose tops and sides would be almost free from surface rivulets during rains, and hence would not be subject to rapid wasting and lowering. Soft sands dredged from the proposed Nicaragua Canal and left in steep piles with surfaces in many cases at the angle of rest have remained for several years almost untouched by surface erosion, although the annual rainfall is over 250 inches, simply because the rain does not run off on the surface but soaks in.

Relation of geology to surface topography.—In some areas the character of the topography is determined largely by the geologic formation outcropping. Along the Mississippi bluffs, for instance, the surface rises abruptly from 100 to 180 feet above the alluvial flood plain. These bluffs are cut by narrow ravines, or "gulfs," as they are locally called, into steep-sided hills whose upper portions are largely prevented from weathering back into gentler slopes by a capping of 20 to 80 feet of loess, which may stand under favorable circumstances, as in the bluffs overlooking the river, in vertical cliffs.

Surface warping.—West of the outcrop of the Lagrange sands the general surface slopes gently toward Mississippi River, having an average elevation of about 400 feet along a north-south belt midway between Tennessee and Mississippi rivers in Tennessee and Kentucky. West of this belt, but some distance east of the Mississippi bluffs, in an area about halfway between the northern and southern boundaries of Tennessee, the average elevation is only about 350 feet. From this area northward the surface rises until along the Kentucky line and for some distance northward into Kentucky it has an average elevation of from 400 to 450 feet. South of the same area the general surface elevation declines until near Memphis it is about 300 feet. The uniformity of the general westward slope of the embayment deposits in Tennessee and Kentucky is thus inter-

rupted toward Mississippi River by a warping that has depressed the southern part of the belt and raised the northern part.

Seismic disturbance.—The fact that this more elevated portion is near the area of maximum disturbance in the New Madrid earthquake of 1811 and 1812 suggests a causal relation between the two, especially since it is known that changes of level in the alluvial flood plain of the Mississippi at that time raised a considerable area of it into a broad, low dome. If 350 feet be somewhat arbitrarily assumed as the normal elevation in this higher area the objection might reasonably be made that from all of the facts known in regard to the detailed topography of the valleys and flood plains of the streams of this region tributary to the Mississippi, it is improbable that scarcely a hundred years ago the region underwent an elevation of 50 or 100 feet, else terracing and ponding would reveal it. It seems more probable to the writer that the region may have been elevated some few feet during the New Madrid earthquake and that during perhaps many previous earthquakes similar changes of level occurred whose aggregate effect has been to raise the general surface to the present level. As stated in detail on page 31, there is evidence that this Gulf embayment region was subject to earthquakes perhaps as early as late Eocene time and probably they have continued at intervals down to the present day. In the same way, although there are no records of sudden depressions or other changes of level since the advent of the white man, the general low level of the region near Memphis may be due to depressions during the same series of earthquake disturbances.

The differences in the elevation of the Tertiary and more recent strata as exposed in the Mississippi bluffs at Memphis and at points farther north to beyond Hickman, Ky., indicate that the region near Mississippi River has undergone differential elevation—in other words, has been warped—and if earthquake movements be thought inadequate to produce the effects seen, more quiet and slowly acting but more general and powerful crustal movement must be assumed as the cause, for the difference in elevation of the strata of these bluffs does not seem due to differences in surface erosion.

Elevation along the bluffs.—In the middle and northern part of Tennessee and into Kentucky the general surface rises somewhat as the bluffs of the Mississippi are approached. At Hickman, Ky., for instance, at the top of the bluff the elevation is 461 feet; while to the east it is from 50 to 100 feet less.

This does not seem to be the case at either Memphis on the south or Wickliffe on the north. The general surface at both these places seems either to be flat toward the east or to rise gently in that direction. The westward rise of the surface in northwestern Tennessee as the Mississippi bluffs are approached may possibly be due

to doming caused by the earthquake activity in this region, as already alluded to or to some more general crustal movements.

EMBAYMENT AREA IN ILLINOIS.

In Illinois the Gulf embayment area includes the southeastern part of Alexander County, all of Pulaski County south of the swamps of Cache River above Ullin, all of Massac County south of the chain of swamps in its northern portion, and a very narrow strip in Pope County along its southern boundary.

This area in Illinois may be divided into two portions that differ from each other in their surface topography and elevation. One portion comprises the low, flat alluvial plains of Mississippi and Ohio rivers. The other portion is a rolling to hilly upland.

Flood plain.—The alluvial plains extend as a broad belt from Santa Fe down the Mississippi to Cairo and thence as a narrow belt up the Ohio to a point a few miles above Mound City, where the upland bluffs on the Illinois side close in on the river and continue with but slight interruption to a point a short distance north of Metropolis. There the flood plain again begins and widens as it extends up the river until it attains a width of several miles in the bend above Paducah. This flood plain extends up the Ohio beyond the limits of the Gulf embayment region.

The elevation of this low plain is about 320 feet at Cairo and about 340 or 350 feet along the edge bordering the upland. In places the alluvial plain and the upland meet along a sharply defined line, the upland surface rising abruptly as a steep-sided bluff. In other places the two types of surface meet and merge with gentler slopes.

Cache River Valley.—The flood plain of Cache River below Ullin is a part of this alluvial plain and is covered by backwater during floods. Above Ullin the valley of the Cache is a continuation of the same plain, though it is bordered on the south by a rolling upland that rises a hundred feet or more above it.

The Cache River valley is an abandoned valley of Ohio River and to this fact it owes its width, flat surface, and low grade. The Ohio formerly turned westward 3 or 4 miles below Golconda and followed the valley of Big Bay Creek for some distance, then continued westward to the present Cache River through the depression now occupied by the chain of swamps in northern Massac County. The Cumberland and Tennessee rivers then united at Paducah and followed the present course of the Ohio from there to Cairo.

Uplands.—The upland region includes all of Pulaski County lying southeast of the Cache River valley and north of the Mississippi and Ohio flood plain, which extends, as has been stated, a short distance north of Mound City. It also includes all of Massac County south of the chain of swamps which crosses its northern part, except the

strip of Ohio flood plain in its southwestern part, and a small area of Pope County adjacent to the Massac County line. The upland has a rolling to hilly surface whose average elevation is 375 to 450 feet above sea level.

GEOLOGY.

GENERAL STATEMENT.

The rocks of the region under consideration consist of sands, clays, and gravels that range in age from Cretaceous to Recent, though the record is not one of continuous sedimentation. These deposits are for the most part unconsolidated. Here and there the sands may be locally cemented in part into an ironstone or ferruginous sandstone and in drilling a well one or more layers of such indurated sandstone are usually found somewhere in the section. These layers are as a rule from a few inches to a foot thick, rarely as much as 2 feet, and are usually found at the bottom of a stratum of sand resting immediately on a bed of clay. Their origin is simple. They are merely the lower portion of the bed of sand, once loose, but now cemented into a firm rock by iron oxide carried there in solution in water and prevented from descending farther by the underlying impervious clay. These thin layers are not thick enough or hard enough to offer any serious obstacle to the driller using tools primarily fitted for work in soft sand and clay. Usually a few blows from a heavy iron rod breaks them to pieces or a chisel point soon cuts through them.

In numerous places, especially on the eastern side of the region, gravels lying on or near the surface have been cemented by iron into a firm ironstone conglomerate. Ledges of this may be several feet thick, but as it lies at or near the surface in the higher parts of the region much of it has been undermined by erosion and either broken into loose blocks or removed entirely, so that it does not form a continuous stratum and rarely offers serious interference to well drilling.

DESCRIPTIONS OF THE ROCKS.

The geologic formations represented in the embayment deposits of this region, given in order from the oldest to the youngest, are the Eutaw sand, the Selma clay, and the Lagrange formation, of the Cretaceous; the Porters Creek clay and the Lafayette formation, of the Eocene; the Lafayette formation of the Pliocene; the Columbia sand, loess, and loam, of the Pleistocene, and the river alluvium, of Recent age. These rest on a floor of Paleozoic rocks.

PALEOZOIC FLOOR.

The rocks that underlie the unconsolidated deposits along their eastern edge near the southern line of Tennessee belong to the Miss-

issippian series of the Carboniferous; in the deep well at Corinth, Miss., chert that apparently belonged to this series was struck at a depth of 450 feet. Northward in Tennesssee the Mississippian series soon disappears and Silurian limestones become the floor of the embayment. These were entered in the well at Lexington at a depth of 500 feet. No other deep wells in Tennessee, however, reach the limestones beneath the embayment sands and clays and their exact depth at other points in Tennessee is not known. To the north, in Benton County, the floor belongs to the Mississippian series, while still farther north, in Henry County, it is again Silurian, but the Mississippian rocks reappear near the Kentucky line and underlie the edge of the embayment through its entire extent in Kentucky and through southern Illinois at least as far west as Ullin. From Ullin westward to Mississippi River part of the marginal floor is Mississippian, part probably Devonian, and part Silurian.

In Kentucky three deep wells have passed through the embayment deposits and entered the Paleozoic rocks beneath. The deep well at Paducah reached the Mississippian at a depth of 324 feet. The one at Wickliffe is reported to have entered the same series at a depth of 1,000 feet. At La Center Mississippian chert was encountered at a depth of 387 feet. In southern Illinois deep wells at Cairo entered the underlying Mississippian chert, or Elco gravel, as it is locally known, at a depth of 525 feet. At Mound City the depth to the chert is reported to be 605 feet. The depth to the Paleozoic floor over the rest of the area under consideration is of much interest in connection with water-supply problems. No direct measurements can be had at present because no other deep wells have gone through the embayment deposits. The well that has penetrated these deposits farthest is the deep well at Memphis, a record of which is given on page 114. The bottom of the well, at a depth of 1,147 feet, is down 121 feet in the Porters Creek clay. If it is assumed that this formation has there its maximum thickness of 175 feet, as observed elsewhere, and that the Ripley formation, Selma clay, and Eutaw sand have their maximum observed thickness, the Paleozoic floor would be reached at Memphis at a depth of about 1,160 feet below the bottom of the deep well, or about 2,300 feet from the surface. At no one place, however, have these formations been found to have each its maximum thickness, but where one is thicker than the average another may be thinner or even entirely absent, so that if there is not an aggregate thickening of these beds as compared with their development in other places, the depth to the Paleozoic floor at Memphis will be considerably less than 2,300 feet—perhaps several hundred feet less.

It should, however, be as clearly borne in mind that one or more of these lower beds may thicken materially or that other formations not

appearing as surface outcrops in this area may be present in the section and make the distance to the hard-rock floor greater than that given above. While deep drilling in loose sands and clays is attended with difficulties, yet if it were thought desirable to explore to further depth the water-bearing deposits underlying Memphis, the boring might easily be carried to a depth of 2,500 feet or more. At Galveston, Tex., a few years ago, a well was successfully sunk through loose sands and clays to a depth of 3,070 feet.

CRETACEOUS SYSTEM.

EUTAW SAND.[a]

Extent.—The Eutaw sand is the oldest of the embayment formations and rests upon the hard rocks of the Paleozoic floor. It outcrops along the eastern edge of the embayment deposits in Hardin and Decatur counties and the extreme southern part of Benton County, Tenn., in a belt whose width varies from 2 to 8 miles and averages somewhat less than 4 miles. In the deeper part of the embayment it very probably extends somewhat farther north than its extreme northern outcrop, but that it does not underlie the entire embayment is shown by its absence in deep borings in the northern part of the area, at Paducah, La Center, Hickman, and Cairo. It is impossible to determine its northern limits beneath the later deposits in the absence of wells deep enough to reach the Paleozoic floor, but it may be fairly assumed that it probably underlies all of the embayment area in Tennessee west of its outcrop. Under most of this area, however, it is at such a depth that there is not much likelihood of wells reaching it, because water will probably be obtained at less depths from overlying beds.

Lithologic character.—The Eutaw beds are composed predominantly of sand, which is, however, interbedded with a subordinate amount of clay. The deposit was formed in shallow water characterized by weak but constantly and rapidly changing currents so that the sand and clay are ever varying in their interbedding. The conditions were not marine, but probably those of brackish water. In a continuous exposure of several hundred yards beds of sand or clay may be seen to grade wholly or partly from one to the other several times, or in a bed of one material a lens of the other may appear and rapidly thicken or may remain a thin layer and disappear in a short distance. In places the sand and clay are interlaminated in very thin layers and in many such cases the laminæ are cross-bedded. The cross-

[a] This formation is here identical with the Coffee sand of Safford, and, while direct tracing to Eutaw localities in Alabama has not been done, it is most probably the close equivalent of the Eutaw of that State. In the Tennessee area it is not thought to include any beds equivalent either to the Tombigbee sand above or the Tuscaloosa below. If the Tombigbee has an equivalent in this area it is most probably included in the basal part of the Selma clay. The Tuscaloosa is not believed to be represented here.

bedding is weak, being usually at a gentle angle only and dying out in a few feet. At no place seen by the writer does it involve a large mass of material in any one spot.

As a result of this abrupt variation in lithologic character no two sections of the Eutaw sand taken a few rods apart will agree in detailed thickness of beds. Just east of Parsons, Tenn., in the railroad cut, there are at the base about 4 feet of conglomerate with angular and rounded chert cobbles up to 8 or 10 inches in diameter, overlain by very dark blue lignitic sandy shales in thin papery layers. These shales are locally interbedded with several layers 4 to 8 inches thick of coarse material, which contains rounded chert masses 4 to 6 inches in diameter and numerous similar-sized angular pieces of Devonian black shale that must have been derived from some Devonian exposure very near by, along the shore at that time. Some rods to the west the lignitic shale passes beneath cross-bedded sands that contain a sprinkling of rounded gravel up to an inch in diameter. These sands are variable in texture and contain occasional thin layers of leaden-gray clay that are persistent for only short distances. Farther west this layer of sand and gravel seems almost to wedge out as it passes beneath track level, and over it lies a fine leaden-gray to dark-blue or purplish clay about 20 feet thick, overlain by about 10 feet of lighter colored sandy clay. Owing to variations in their thickness and the lowness of the banks of the cut, the average thickness of several of the lower beds described above can not be determined, but is perhaps 10 to 20 feet each.

Section.—The best exposure of the Eutaw sand is found at Coffee Bluff, on the west bank of Tennessee River in Hardin Country, Tenn. The river washes the foot of the bluff for nearly 2 miles, but at no point is the base of the formation shown, so the exact thickness there can not be ascertained. At the point where the highway reaches the top of the bluff the following section was obtained:

Section at Coffee Bluff, Tennessee.

	Feet.
1. Back half a mile west of the edge of the bluff, red and yellow chert gravels of Lafayette age with overlying reddish sandy clay	15
2. Along descending slope of road from above point to the edge of the bluff are poorly exposed light-colored sands and leaden-colored clays interbedded in thin layers which are usually minutely laminated	120
3. At top of bluff, light-colored sands similar in color, texture, and structure to those below	12
4. Dark slate-colored clay in thin laminæ, usually a very pure and fine-grained clay, but in places with thin, sandy layers. It contains small fragments of indistinct plants and shows at its base local unconformity with the underlying beds	25
5. Fine gray sand interbedded with slaty or leaden-colored clay in fissile papery laminæ. The sand and clay are often interlaminated and more or less cross-bedded; in places a relatively pure bed of sand or clay several feet thick grades over along the bedding plane into the other within a few yards. On the surface of the thin fissile shales are indistinct leaf impressions.	

	Feet.
The sand and clay alike carry more or less lignitized wood, which is in small pieces except in the lower part of this division, where logs of it are found. Decomposing pyrite is associated with the lignite. Two logs of petrified wood projected from this sand and clay when Safford made the measurements recorded on page 412 of his Geology of Tennessee. These have since disappeared by the recession of the bluffs from undercutting by the river. Some of the sand is flecked with fine mica particles. In places a tendency to induration is noticeable in the sands, though generally they are rather soft. The cross-bedding is always on a small scale and frequent reversals of direction are to be seen	40
6. Sand varying in color from light gray to canary yellow, micaceous	3
7. Sand, gray and lignitic, with much decomposing pyrite, to water's edge	15

The more lignitic sand and clay showed in many places white and yellowish-brown incrustations, due to efflorescence by the sulphates and other salts resulting from the decomposition of the pyrite. The water trickling from these beds along the face of the bluff was charged with iron salts and was precipitating hydrated iron oxide, which covered the ground as a red or yellow slimy scum.

At Crump and Pittsburg Landing, 4 and 8½ miles, respectively, south of Coffee Bluff, are imperfectly exposed sections of the Eutaw sand. These sections show interbedded sands and clays very similar in appearance to those in the lower part of Coffee Bluff. Some of the sand at Pittsburg Landing is locally cemented into a loose ferruginous sandstone.

Dip and thickness.—The Eutaw sand dips westward at a low angle and passes beneath the Selma clay. No exact measurement of its thickness has been made. The best partial section is that at Coffee Bluff given above. Over 215 feet are exposed there, but the exact thickness is not known, as the strata dip slightly westward in the half mile that the upper part of the section stretches back from the bluff. The base is not exposed at low water, but the underlying Paleozoic limestones outcrop some distance downstream and also above, at Savannah, on the opposite bank, almost in line with Coffee Bluff. It is probable that at the bluff not more than 25 to 50 feet of the sand are beneath low-water level, and if a slight allowance be made for the low westward dip in the upper part of the section the formation is not far from 250 to 275 feet thick. The deep well at Lexington passes entirely through it, but unfortunately the position of its top could not be determined from the record given—from memory, as usual—by the driller. A well at Corinth, Miss., seems to have entered it at 90 feet according to one record and at 150 feet according to another record. This would make the Eutaw sand either 360 feet or 300 feet thick, as the underlying rock was reached at 450 feet. Other records at Corinth make it more likely that the formation was entered at a depth of 90 feet and that it is consequently 360 feet thick there.

SELMA CLAY.

Extent.—The Selma clay rests upon the Eutaw sand and outcrops in a belt 6 or 8 miles wide that enters Tennessee from Mississippi and extends northward about halfway across the State. (See Pl. I.) Like the Eutaw sand, it then disappears, and while it may extend some distance farther north beneath the later Gulf embayment deposits there are no means of proving such to be the case. The problem of its northward extension corresponds to the similar problem discussed under the Eutaw sand (p. 23). The wells at Paducah, La Center, Hickman, and Cairo show the absence of both the Eutaw and the Selma.

Lithologic character.—The term Selma chalk, applied aptly enough in Mississippi and Alabama, is scarcely appropriate in Tennessee, where the formation is a clay that is light leaden gray or greenish when dry and somewhat darker colored when wet. Certain parts are a darker green from the presence of grains of glauconite. Fossil shells are common and in some places are so large and abundant that they have often been gathered and burned for lime. Throughout the formation, which is very uniform in character, the clay contains a considerable amount of lime, derived from the decay of the fossil shells, and very near or just at the base are usually found one or more thin layers of clay or greensand, indurated by the presence of the lime. Some layers are nearly free from the glauconite or greensand; in others it is fairly abundant. The formation was deposited under marine conditions.

When this clay is wet and unaffected by surface weathering it is often blue and is described by the well drillers as "blue dirt." Near the surface in natural exposures it weathers to a yellowish-green clay, that is exceedingly sticky when wet and that on drying shrinks and cracks open, so that it is known as "joint clay."

The clay is somewhat sandy, but no beds even approaching a pure sand were found in it. Water percolates through it slowly. Very much of the rainfall runs off on the surface and this is believed to explain the absence in so much of its outcrop area of beds of surficial gravel and sand, such as rest on the adjacent formations both to the east and to the west. The removal of these surficial gravel deposits is discussed more fully under the heading "Origin of the topography" (p. 17).

Thickness.—Near the Mississippi line the formation is between 350 and 375 feet thick. At Selmer, Tenn., it is 375 feet thick. To the north it thins to 100 feet or less before it disappears. In the deep well at Lexington, Tenn., the Selma clay and the underlying Eutaw sand are together 300 feet thick. The driller did not note any change in passing from one to the other, but this is not greatly to be wondered at, since east of Lexington along the railroad to Parsons the Eutaw sand contains much dark-gray clay.

RIPLEY FORMATION.

Extent.—The Ripley formation extends across both Tennessee and Kentucky into southern Illinois and there curves westward. Its exact western extent in Illinois was not determined, partly from lack of time, but mainly because of the scarcity of outcrops due to the thickness of the overlying Lafayette and loess deposits on the uplands and of the alluvium on the Mississippi River flood plain. It is probable that the Ripley formation extends across to the Mississippi at Thebes, Ill., and is the sand described as overlying the Silurian limestone just above that place, though this sand may be a part of the Lagrange formation.

The belt occupied by the Ripley outcrop is about 12 miles wide at the southern boundary of Tennessee. To the north it narrows to about 8 or 9 miles in the center of the State and to 6 miles along the northern boundary. This width is maintained in Kentucky and is exceeded in southern Illinois.

Lithologic character.—Lithologically this formation bears considerable resemblance to the Eutaw sand. It is, however, composed more largely of sand and, at least in surface exposures, is predominantly lighter in color. The stratified sands of the Ripley show in some sections a considerable variety of colors, usually red, pink, light yellowish brown, and gray. With the sands are found beds of gray, leaden, or slate-colored clay 10 to 20 feet or more thick. In places the sand and clay are interbedded in thin layers. The sands are usually medium to fine-grained, and soft and incoherent. Induration by iron is, however, a prominent feature in certain places.

Many of the clay beds contain lignite, either in separate pieces or in thin beds of local development. Partly rotted and unidentifiable leaf remains are common. In a few places well-preserved leaf impressions were found, as, for instance, on the "sandhill" road east of Benton, Ky., about halfway up the ascent from the bottoms of East Fork of Clarks River to the uplands.

The sands contain a larger proportion of iron than any other formation in the region except the Lafayette. Part of this iron near the surface is peroxidized and colors the sands a deep red, which is very much like the color so often found in the sands of the Lafayette formation (see p. 42). This makes it difficult to determine the contact between the Ripley and the Lafayette, which generally overlies all the older formations. For instance, the contact is very obscure in the "big cut" (Pl. II, *A*) on the Southern Railway and has been a source of uncertainty and error in the interpretation of the section found there.[a]

The larger part of the iron occurs as a cement for the sands at cer-

[a] See Hilgard, E. W., Geology and Agriculture of Mississippi, 1860, p. 16; Safford, J. M., Geology of Tennessee, 1869, p. 418.

tain horizons and has converted them into sand ironstone that assumes a variety of shapes, some of which are unusual. A common form is the firm sandstone made by the cementing of several feet of sand by iron. Thin platy layers of ironstone also occur. Some of these are flat; others are curved into odd and fantastic shapes. At certain horizons concretionary ironstone tubes or pipes are found. These may be long, straight, separate pipes of uniform size and thickness or somewhat irregular and more or less flattened and united into a honeycombed mass, in which the tubes are parallel. Several horizons of such honeycombed ironstone concretions are to be seen in the "big cut," of which a section is given (see Pl. II, *B*.) Here these concretions form ledges that hold up the sides of the cut from caving.

In general, the sandstone layers or the plates or tubular masses become exposed by erosion and then act as a protection against further erosion. It is partly for this reason that the outcrop of the Ripley sand forms an elevated ridge that is very conspicuous in northern Mississippi and extends for a number of miles into Tennessee before it dies down into an elevated belt that usually forms the divide between the Tennessee and Mississippi River drainages. Another reason for the greater elevation of this and other sandy belts as compared with adjacent clay areas is the fact that a much larger proportion of the rainfall soaks into the sand than into the clay and so does not erode the surface. (See p. 17.)

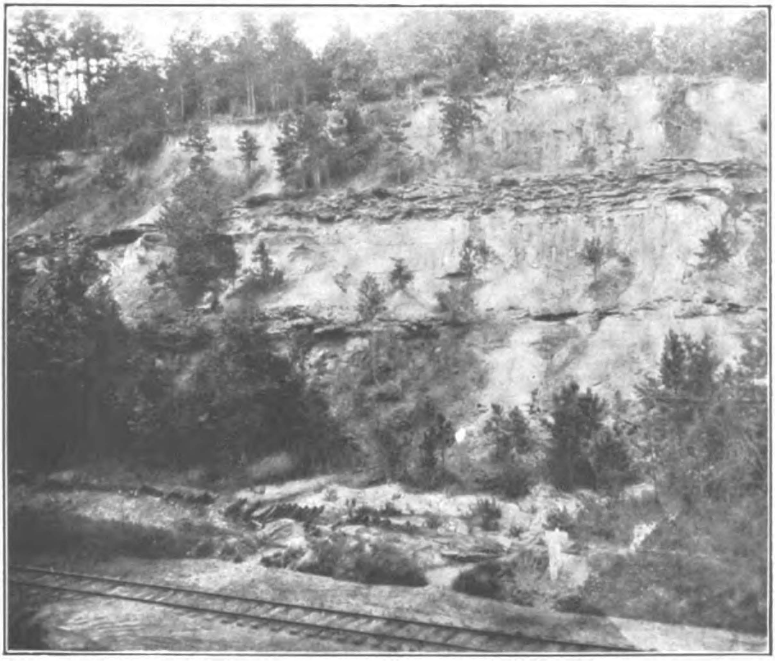
In deep wells the sands are not usually so oxidized as in surface outcrops and so show grays or dark colors instead of the light ones mentioned above.

In some places, especially in Kentucky and in Massac County, Ill., the Ripley contains beds of clay suitable for pottery purposes.

Fossils.—No fossils other than plant remains are found in this formation in the area under consideration.

From this fact and from its lithologic character it is believed to be of nonmarine origin. It was deposited in fresh or brackish water here, but farther south in Mississippi marine conditions prevailed. The beds of impure limestone just east of Middleton, Tenn., containing remains of marine fossils and tentatively assigned by Safford to the top of the Ripley, are now known to belong to the Eocene. The plant remains found in the Ripley are usually fragmentary and unrecognizable. Its stratigraphic relations, however, and its continuity with strata in Mississippi that contain marine fossils make its Cretaceous age evident. It is the youngest Cretaceous formation of the region.

Section.—The best section of the Ripley formation is to be seen in the deep cut through the "big hill," 1½ miles west of Cypress station,



A. RIPLEY SAND IN THE BIG CUT, TENNESSEE.

B. TUBULAR SAND-IRONSTONE MASS IN RIPLEY SAND IN THE BIG CUT, TENNESSEE.

Tenn., on the Southern Railway. This section from the top downward is as follows:

Section of Ripley formation near Cypress, Tenn.

	Feet.
1. Red case-hardened Lafayette sand and clay, with a few broken pieces of ferruginous sandstone and scattering quartz pebbles marking the contact with the underlying Ripley	8
2. Fine red sand and clay, with rolled clay pellets and thin streaks of white clay	20–25
3. Concretionary tubular sand ironstone in single pipes or in masses of parallel ones, with soft sand cores	2–8
4. Fine variegated sand, having, as a whole, a light grayish color, but showing in detail red, white, brown, yellow, and purple streaks or mottling. Case-hardened, so that it breaks off in large masses	20
5. Ferruginous sandstone pipes and fluted masses as above	0–5
6. Fine sand and clay interbedded in thin laminæ; yellow, brown, cream, or gray; sands micaceous; leaf and other plant markings common but indistinct and unidentifiable, exposed down to 15 feet below track level	35

Dip and thickness.—The dip of the Ripley in Tennessee and southern Kentucky is, like that of the older formations, at a low angle to the west. In northern Kentucky it is southwest and in Illinois it is south. Its exact thickness in southern Tennessee is not known, but it is probably 500 feet. At Paducah, Ky., 204 feet of it were found in the deep well, and to get its entire thickness there probably 100 feet should be added to this for its eroded upper part. At Cairo, Ill., it is only 25 to 54 feet thick. At Wickliffe, Ky., it is reported to be 400 feet thick.

TERTIARY SYSTEM.

EOCENE SERIES.

PORTERS CREEK FORMATION.

Extent.—The Porters Creek formation, the oldest of the Eocene rocks of the region, rests unconformably on the Ripley sands of the Cretaceous and outcrops immediately west of the Ripley in a belt that is about 8 miles wide, in southern Tennessee, but averages only about 4 miles in width across the State. In Kentucky it widens out again, reaching 10 or 12 miles in northern Calloway County. The outcrop narrows much as it curves westward beyond Paducah and is concealed by the alluvial deposits of Ohio River before crossing into Illinois. In Illinois it is known to outcrop only along the bank of the Ohio, at Caledonia Landing, and for some distance to the north toward the Grand Chain. The exposures are for the most part poor, however, and its identification is made partly by a few indistinct fossil casts but mainly by the presence of greensand, which is absent from the Ripley below and the Lagrange above, but which is found in the lower part of the Porters Creek. Farther west across southern Illinois its outcrop is obscured by either the Lafayette gravels and the

loess or by the alluvial deposits of the Cache and Mississippi River bottoms.

Lithologic character.—The formation is composed mainly of a fine-grained clay that is very dark gray or in places almost black when wet, but which becomes a light gray on drying. It is familiarly known in the region as soapstone. Interbedded with this clay are sometimes found, especially in the lower part of the formation, beds of fine, micaceous, silty sands, which are usually indurated into soft sandstones. The lower part of the formation also contains, interbedded with the gray clay and micaceous sand, beds of greensand that may contain enough calcareous matter to cement certain layers into impure limestone. The calcareous matter has doubtless been derived from marine shells, the hollow impressions of which are abundant in some of the more calcareous beds. Such beds have been found near the base of the Porters Creek formation at intervals from a point just east of Middleton, Tenn., nearly to Paducah, Ky.

At several places the leaden-gray clays and the greensands of the Porters Creek formation are intersected with sandstone dikes. These dikes vary in width from a fraction of an inch to as much as 2 feet, though the average width is only a few inches. In places they seem to occur singly and the few thus seen were wider than the average and ran in straight lines. More commonly a large number of small dikes occur together. These may run in any direction and are apparently without any system in their orientation. Some members of a group are persistent in direction and fairly constant in width, while others vary in direction and width and throw off branches that may end blindly or may curve and unite again with the main dike. The various dikes of a group intersect at almost any angle.

Some of the dikes show slickensided surfaces with vertical striations, and a few of the slickensided dikes show cracks produced by shearing that resulted from the differential movement of the rocks on either side of the dike. The faulting thus indicated is believed to have been of very small amount. In only two cases was it possible to ascertain by any discontinuity of beds that faulting had occurred. In these the amount of movement was between 1 foot and 2 feet only.

The sandstone filling these dikes is a soft, fine-grained, micaceous, silty rock similar to that interbedded with the clays of the formation. The dikes contain casts of marine invertebrate fossils similar to those found in the sandstone beds. In both cases all trace of shell substance has disappeared, but distinct impressions are left.

From the lithologic similarity and from the identity of the fossil casts it is believed that the material of the dikes was derived from the micaceous sandy beds of the formation, and that it was injected into the openings where it is now found while still an unconsolidated sand, whose mica particles would in the presence of water convert

it into a very mobile quicksand and enable it to flow into the fissures without crushing to pieces the delicate shells it contained. This injection very probably occurred shortly after these beds were deposited, as it was evidently before the sand had become consolidated into a sandstone and before the calcareous matter of the shells contained in it had been removed by leaching.

The size, number, and relations of the fissures to each other lead to the belief that they are not the result of shrinkage of the sediments during consolidation, but that they were produced by earthquake disturbances in Eocene time not long after these beds were deposited, and that the micaceous sand was forced upward along with water into these cracks during the disturbances, just as in this same region the embayment deposits were much fissured during the New Madrid earthquake of 1811 and 1812 and sand and water, often in large quantities, were forced up through these fissures to the surface.

The sands in the Porters Creek tore off pieces of the clay from the walls of the fissures as they were forced up, and these pieces of clay, some rounded slightly but most of them still sharply angular, are found to-day as inclusions in the sandstone dikes. The sand thus injected became indurated, and it is probable that the slight faulting that produced the slickensiding and the shearing seen in some of the dikes was the result of another and later period of earthquake disturbance.

In Mississippi McGee[a] has recognized and described similar dikes. In Kentucky Loughridge[b] saw in a number of places dikes of sandstone in the Porters Creek, though he failed to recognize their true nature. Safford[c] apparently did not recognize them, nor did Harris,[d] though both evidently saw them—Safford near Wade Creek, where the writer first saw them, on the road from Bolivar to Purdy, and Harris at Crainesville, a few miles away. Harris describes them as sandstone concretions.

Thickness and dip.—The thickness of the Porters Creek, according to the best measurement available—that in the well at Jackson, Tenn.—is about 175 feet. At Wickliffe, Ky., it is 158 feet thick, and farther north, near the northern edge of the area, where it has probably suffered from erosion, its thickness is 124 feet at Cairo and 100 feet at Mound City, Ill. At Huntington, Tenn., the wells show 65 to 70 feet of it, but this may not be the full thickness there, as the wells probably start below the top. Just south of Paducah, Ky., a well has gone 140 feet into it without getting through it, and the deep well at Memphis, after penetrating 121 feet of it, stopped without getting through. It is very probable that the underlying Ripley

[a] McGee, W J, Bull. Geol. Soc. America, vol. 1, 1890, p. 440.
[b] Loughridge, R. H., Jackson Purchase Region, 1888, pp. 44, 252, 287.
[c] Safford, J. M., Geology of Tennessee, 1869, p. 423.
[d] Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, 1896, p. 18.

sands would be reached in this well in less than 100 feet more. The dip is at a low angle to the west in Tennessee and averages for the section east of Memphis 22 feet per mile. It changes in Kentucky and southern Illinois to the southwest and the south, respectively, and increases in amount a few feet per mile.

Age and nomenclature.—Marine invertebrate fossils from the band of impure limestone and the calcareous greensand near the base show the fauna to be of lower Eocene age. A few casts from the Huddleston farm, near the mouth of Wade Creek, 8½ miles east of Bolivar and 2½ miles west of Crainesville, Tenn., were sent to Dr. W. H. Dall for identification. He reported *Crassatellites productus* Con., *Protocardia lenis* Con., *Venericardia alticostata* var. Con., and *Cucullæa macrodonta* Con. as recognizable and referred it to the upper portion of the formation, called by Harris and older authors the Lignitic, probably about E. A. Smith's Bashi series.

From the locality just mentioned Harris made a larger collection than the writer and has also collected extensively from the same beds at several other localities in the immediate neighborhood. The description of these localities and lists of the forms found are given in his monograph on the Midway stage.[a]

In 1860 Safford sent Gabb collections from these same beds made at three points in the vicinity of Middleton, Tenn. They were described by Gabb,[b] the impression then being that they were of Cretaceous age.

Occasional plant remains have been reported from the clays of this formation. In a cut on the Southern Railway at milepost 480.5, about a mile east of Middleton, Tenn., the writer found, in a bluish sandy clay containing some greensand, both casts of marine invertebrates and scattering leaf impressions, the latter somewhat fragmentary, but well enough preserved for identification. From want of time and from the fact that the geologic horizon was definitely known from the invertebrate remains, no collection of these leaves was made, though the locality would be a favorable one for correlating this Eocene fauna and flora, which were evidently contemporaneous.

Safford later recognized the Eocene age of the thin limestone east of Middleton at or near the base of this formation and proposed for it the name Middleton formation.[c] No definite upper limit, however, was set for the formation, though it apparently was meant to include only the calcareous beds. Since these calcareous beds are not sharply separable from the more purely argillaceous beds above, and since both together form a unit so far as all water-supply problems are concerned, it is thought best to regard as one formation the impure limestones, greensands, silty sandstones, and light leaden-colored clays

[a] Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, 1896, pp. 18-22.

[b] Jour. Acad. Nat. Sci. Phila., new ser., vol. 4, pp. 375-406.

[c] Safford, J. M., Notes on the Middleton formation of Tennessee, Mississippi, and Alabama: Bull. Geol. Soc. America, vol. 3, 1892, pp. 121-123.

that extend from the Ripley sands below to the Lagrange sands above and for these rocks to retain the geographic name Porters Creek, early proposed and used by Safford. It is the equivalent of the Flatwoods of the Mississippi geologists.

LAGRANGE FORMATION.

Of all the deposits in the area discussed the Lagrange is the thickest, covers the largest area, shows proportionally the least actual surface exposure, and is the most variable in composition and the most doubtful as to its exact age. It has in the past been the most puzzling to geologists and has led to the most errors on their part. Aside from the interest these facts give it, it is and always will be the most important of these formations as a source of water supplies because of the wide area underlain by it, the unusually good quality and quantity of the water it contains, and the moderate depth at which the water may usually be obtained.

Extent.—The eastern edge of the Lagrange formation extends from the southwestern part of Hardeman County, Tenn., north-northeastward through Chester, Madison, Henderson, Carroll, and Henry counties, Tenn., and southwestern Calloway, northeastern Graves, middle McCracken, and northern Ballard counties, Ky. It then passes westward into Pulaski County, Ill., not far south of Caledonia Landing. It is not possible to follow it westward across Pulaski and Alexander counties, because it is concealed beneath later deposits.

All of the area under consideration in this paper lying west and south of the line thus traced is underlain at no great depth by the Lagrange formation. The territory thus embraced is somewhat over two-thirds of the total area discussed. Although underlying so large a territory it forms the actual surface of but a small part, since on the uplands it is concealed by the Lafayette and the loess and loam, and in the Mississippi bottoms its upper part has been cut away to some extent by the river and then covered with alluvial deposits. At many places on the uplands the thin overlying deposits are cut through by streams and railways, so that abundant opportunities are presented for studying it and determining its extent.

Lithologic character.—The formation consists of interbedded sands, clays, and lignitic material. Much the larger part is sand, which is mostly fine grained, though here and there throughout the formation beds of medium or coarse sand or even gravel may be found. Such coarser beds do not seem to be continuous over any large area. While it is probable that if a coarse bed is struck in one well at any given depth it will also be found in other wells in the immediate vicinity, yet at Memphis beds reached by one well have not been found in other wells only a block or two distant.

The sands exposed to view are usually strongly cross-bedded and were deposited under brackish-water conditions in a sea characterized by strong and ever varying currents, so it is not strange that coarse sand or gravel found in one spot should be wanting a short distance away. The sand is usually sharp grained and much of it is so fine that it can not be kept out of deep wells even with the finest strainers. The color of the sand is usually a cream or light orange, though in many places streaks of it show rusty browns, light pinks, or light purples. In exposed sections these colors may wash out during rains and color all of the surface beneath them so as to give erroneous impressions as to the real color of much of the section unless it is examined by digging into it. In places the sand is darkened by lignitic material and may appear gray or grayish black.

The clays of the Lagrange vary from pure, fine-grained plastic material to sandy, silty clays that are often dark from organic matter or black from lignite. The clays of the lower part of the formation are characteristically fine grained, pure, plastic, and either very light colored or white. Chemically they are highly siliceous. Without doubt they have resulted from the thorough disintegration of the cherts of the surrounding Paleozoic land surface, which furnished the waste to the sea of that day.

The plastic, siliceous clays occur as lenses embedded in the sands and are found outcropping in a belt along the eastern part of the Lagrange area in both Tennessee and Kentucky. At numerous places they are mined and either used in local potteries or shipped in the raw condition to other States. Many of the beds contain great numbers of beautifully preserved leaf impressions and numerous collections have been made of these remains. The writer made collections at Grand Junction, Tenn., and at Hickman and Wickliffe, Ky. These were submitted to F. H. Knowlton for identification, and his detailed report is given on page 38, in the discussion of the age of the beds here included in the Lagrange. The clays mined in Pulaski and Massac counties, Ill., appear to belong not to this but to the Ripley formation, since they are found north of the outcrop of the Porters Creek formation along the Caledonia bluff.

The Lagrange is here made to include all of the beds between the Porters Creek clay beneath and the Lafayette gravel above. In contrast to the white plastic clays which characterize the lower part of it and outcrop near its eastern margin, dark-colored lignitic clays are often very prominent in its upper part and are exposed along the Mississippi bluffs or are penetrated in wells in the western portion of the area. At Memphis, for instance, there is a bed of blue clay about 150 to 200 feet thick at the top of the formation. At Randolph, Tenn., the lower part of the bluff is composed of dark lignitic clays with beds of lignite. At Hickman, Ky., the upper part of the for-

mation is composed of fine-grained leaden-gray siliceous clays underlain by darker lignitic sandy clays. Wells at several other places near the Mississippi bluffs report dark clays or silts in the upper part of their sections. The dark-colored clays found at these various places are not, however, lithologically similar, and wells here and there in the area just east of the Mississippi bluffs fail to report it, but give sands instead in the upper part of the section. This indicates that there is not a uniform bed of clay overlying the light-colored cross-bedded sands familiar in Lagrange outcrops farther east, but that there are several clay or sandy-clay lenses, the one at Memphis being unusually thick and uniform in character, overlying the more purely sandy part of the formation and making up its upper portion.

The writer attempted to separate this upper clay portion from the lower part of the Lagrange and treat it as a distinct formation. It could not be traced by means of well records, and as the Lafayette gravel almost everywhere conceals all underlying beds in a belt 10 to 30 miles wide east of the Mississippi bluffs, it was impossible to trace it by surface exposures, except perhaps by such an amount of detailed work as was clearly out of the question in the time available. The effort to establish the clay as a separate formation, therefore, had to be abandoned. It is entirely possible or even probable that the upper part should be separated from the middle and lower parts and after very detailed work criteria may be forthcoming for this discrimination. At present it is impracticable and all the beds are lumped together, though certain facts brought out under the discussion of the age of the Lafayette (p. 40) render it probable that the upper clay is considerably younger than the plant-bearing clays in the lower part of the formation at Grand Junction, Tenn., and elsewhere.

Lignitic material is found throughout the formation, but is more abundant in the upper part, in the dark clays just described. In the clay pits in the lower port of the formation macerated and unidentifiable leaf remains occur in certain layers in such quantities as to make them look like rotten strawboard, as, for instance, in the pits just east of Grand Junction, Tenn. In places thin beds of lignite are reported in the lower part of the formation. Beds of lignite several feet thick near the top of the formation have been reached in numerous deep wells in the western parts of Haywood and Weakley counties, Tenn., and a number of natural exposures are known along the Mississippi bluffs. Years ago attempts were made at several places to mine the lignite, but were unsuccessful.

Section.—Admirable exposures of this formation are to be found at and near the town of Lagrange, Tenn., from which it takes its name. Lagrange is situated on a high divide running east and west, with a steep southward slope that forms the northern valley wall of Wolf River and overlooks both the river, flowing a mile away and 200 feet

below it, and the gently rising surface on the south side of the river which stretches back for miles befor attaining the elevation of the north side.

Erosion is rapidly attacking this steep southern slope and ravines 100 to 150 feet deep are eating northward into the divide and undermining houses in the town of Lagrange. These ravines branch and rebranch a number of times, and in their ramifications present admirable opportunities for study not only of the Lagrange but also of the overlying Lafayette and Columbia formations. A view taken here is shown in Pl. III, *A*. The section exposed in these ravines in the southern edge of the town, on either side of the road leading south of Wolf River, is as follows:

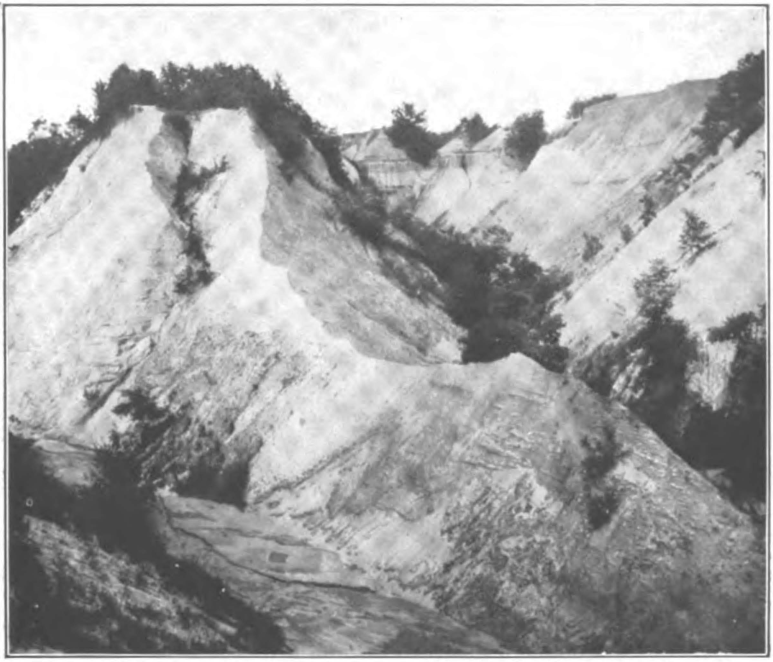
Section at Lagrange, Tenn.

	Feet.
Columbia:	
1. Soft, loose, light-yellow to light-gray sands, cross-bedded	15–18
2. Soil layer, dark with organic matter	1
Lafayette:	
3. Massive bed of brick-red sand, case-hardened, showing very even top but very irregular lower surface and resting unconformably on the underlying sand.	4–15
Lagrange:	
4. Soft cross-bedded sands, mostly fine but in places coarse, of various light colors such as nearly white, light yellow, faint pink, and faint purplish with a few thin crusts and small rounded or short tubular concretions of sand ironstone in places. Near the top there is a clay lens of irregular shape ranging up to 8 or 10 feet thick	100

The lower part of the section is included by McGee[a] in the Lafayette, which throughout northern Mississippi and western Tennessee he considers as usually tripartite, the upper division being massive, case-hardened, loamy, brick-red sand, and the middle and lower divisions being softer, brighter-colored sand, often with clay lenses or beds containing leaf impressions. He would place the lower 100 feet of the above section in the middle and lower divisions of the Lafayette and regard the entire Lafayette at Lagrange as 200 feet or more in thickness. Elsewhere in the same paper, however, he expresses some doubt as to the correctness of this conclusion.

In the writer's studies of the Lafayette from Maryland southward across the intervening States into Georgia, thence westward at intervals into Tennessee, and thence northward in more detail into Illinois, he has never found it to contain clay lenses with plant impressions, nor indeed any fossils, except those of other ages mechanically introduced into it. The Lafayette proper should doubtless be limited, as Hilgard and others limit it in northern Mississippi, to the uppermost of McGee's three divisions, and his lower divisions recognized as belonging to some older formation, which in the section given above is the Lagrange. Further remarks concerning the lim-

[a] McGee, W J, The Lafayette formation: Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, p. 462.



A. RAPID EROSION IN LAGRANGE FORMATION AT LAGRANGE, TENN.

B. LAGRANGE AND LAFAYETTE FORMATIONS AND LOESS IN CUT AT RIPLEY, TENN.

itations of the Lafayette are given under the head of that formation (p. 42), and under the Columbia (p. 46) reference is made to the soil layer and overlying sands seen in the Lagrange section.

Good exposures of these Lagrange sands and clays may be seen at many other points. The clay pits and ravines near Grand Junction, Pinson, and Paris, Tenn., and Boaz and Mayfield, Ky., afford good opportunities for examining them. Exposures of a few feet are found at numerous places near Wickliffe, Ky., and an excellent section of 80 to 90 feet is presented in the bluff at Columbus, Ky., showing all of the characters of the typical Lagrange.

At Hickman, Ky., the bluff is composed almost entirely of fine-grained, jointed, blue to leaden-gray siliceous clay that extends from 30 feet above ordinary water level in the Mississippi upward 75 feet and is overlain by 10 feet of Lafayette gravel, and that by 65 feet of loess. This leaden-gray clay contains numerous small calcareous concretions, but no fossils of any kind were found in it. Beneath it and extending down to and below water level are 30 feet of soft sandy clay, containing much disseminated vegetable matter and identifiable leaf impressions. A collection of these leaves was made and sent to F. H. Knowlton, whose determinations are given on page 38.

The 75 feet of leaden-gray clay in the Hickman bluff differ lithologically very markedly from the usual type of Lagrange sediments. The underlying 30 feet are more nearly like the material commonly seen in the Lagrange in this vicinity, as, for instance, in the lower part of the Illinois Central Railroad cut at Curve, Tenn., a section of which is given under the Columbia (pp. 44, 93), and in the lower part of the section at Randolph, Tenn.

Age.—Nowhere in the region under discussion have marine fossils been found in the Lagrange. At various places, however, the abundant plant remains found often so beautifully preserved in the clays of the formation have been collected and studied by paleobotanists, and paleontologic evidence as to the age of the formation is limited to the results obtained from such study. The writer made collections from four localities while in the field. One of these was from a clay lens in the lower part of the bluff at Columbus, Ky. The second was from the 30 feet of sandy clay just above water level in the bluff at Hickman, Ky. The third was from a light-colored indurated clay found in the south bank of the small stream in the southern edge of Wickliffe, Ky. This spot is the one from which a collection was made for the Kentucky Geological Survey and pronounced by Lesquereux to belong to the Lignitic.[a] The fourth locality is a southward sloping hillside on the road about halfway between Lagrange and Grand Junction, Tenn., where leaf-bearing clays are well

[a] Loughridge, R. H., Jackson Purchase Region, 1888, p. 198.

exposed in numerous recently cut gullies. These collections were sent to F. H. Knowlton, whose report on them is as follows:

The present collection consists of a large number of leaves very beautifully preserved, for the most part in fine-grained plastic clay, occasionally in a more sandy clay. The collection has been very carefully made, and the collector is to be congratulated on the highly satisfactory manner in which it comes to hand for study.

Fossil plants from this general region have long been known, the first collection to which scientific attention was directed being apparently that described by Lesquereux from near Somerville, Fayette County, Tenn., obtained by J. M. Safford, and from the banks of Mississippi River near Columbus, Ky., collected by Owen and Lesquereux.[a] The species, of which several were described as new, were not figured in Lesquereux's paper, but ten years later (1869) were incorporated by Safford into his Geology of Tennessee [b] and a single plate devoted to them. Not all the new species were figured even at this time, but in working up a collection of plants from the Tertiary of Mississippi Lesquereux took occasion to describe and figure several species from Lagrange, Tenn., which were regarded as of the same age as those from Mississippi.[c] Nearly twenty years later two small collections made in the interest of the Kentucky Geological Survey were described by Lesquereux.[d] One of these was from Boaz station, Graves County, Ky., and the other from Wickliffe, Ballard County, Ky. Remarks on the age of the beds at these localities will be made later.

The present collection embraces fossils from four localities, as follows:

1. Columbus, Ky. This material, a white sandy clay, contains two species of *Quercus* and apparently a single species of *Salix*, none of them, so far as I can make out, being identical with the forms mentioned by Lesquereux from this locality. Probably a more extended search among living species would show affinities with these, but this I have not been able to give at this time.

2. Hickman, Ky. This is also a sandy clay, and embraces three forms—a single leaf each of a *Salix?* and *Menispermum canadense* L. and the balance a compound leaf of what appears to be *Tecoma radicans* L., or something near it.

3. Wickliffe, Ky. The largest and best lot, affording the following forms:

Salix angusta Al. Br.
Salix sp.
Quercus saffordi Lesq.
Quercus neriifolia Al. Br.
Quercus moorii Lesq.
Quercus n. sp.?
Myrica copeana Lesq.
Eucalyptus n. sp.
Sapindus angustifolius Lesq.
Sapindus dubius ? Unger.

4. Near Grand Junction, Tenn. The same kind of material as the last, containing the following:

Monocotyledonous plant (fragments).
Salix angusta Al. Br.
Quercus (2 species).
Juglans saffordiana? Lesq.
Sapindus angustifolius? Lesq.
Sapindus sp.
Cinnamomum? sp.?
Ceanothus meigsii Lesq.
Acacia sp. (nov.?).

In Lesquereux's original publication the beds at Somerville and Columbus were referred to the Pliocene, as was that at Boaz station, but later he regarded the deposits at Somerville as "most intimately related to the Miocene of Europe." Safford in his Geology of Tennessee inclined to the opinion that the Orange sand, which included the Somerville bed, should probably be regarded as Eocene, and apparently Lesquereux accepted this determination, for in his report on the Mississippi plants he referred them to the so-called Eo-Lignitic. The Wickliffe deposit was referred by Lesquereux directly to the lower Eocene.

Coming to the present collections, I see no reason to question the correctness of referring the Columbus fossils to the Pliocene, although I have not been able to identify any of the

[a] Am. Jour. Sci., 2d ser., vol. 27, 1859, pp. 363-366.
[b] Op. cit., pp. 425-428, Pl. K.
[c] Trans. Am. Philos. Soc., vol. 18, 1869, pp. 411-530. Pls. XIV-XXII.
[d] Proc. U. S. Nat. Mus., vol. 11, 1888, pp. 11-13, Pl. IV.

forms present with those mentioned by Lesquereux. The apparent preponderance of living species would make it unlikely that the age should be older than Pliocene. The plants from Hickman, Ky., although not identical with those from Columbus, are so modern in appearance that I regard them as Pliocene in age.

The plants from Wickliffe and near Grand Junction are similar in appearance and I regard them as of the same age, but their exact position is at present a little uncertain in my mind. That they are of the same age as those from Mississippi is hardly to be questioned, and I suppose they are to be regarded as "Eo-Lignitic" or Eocene, but they are so well preserved and in general so modern in appearance that I can not rid myself of the notion that they should be placed in the Miocene. However, I have not seen any of the field relations and so can not well define this impression. They are the same forms as those from Mississippi and belong to what has been called Orange sand or Eo-Lignitic, but they seem quite unlike other Eocene floras with which I am familiar.

There would seem to be no question that the bed near Grand Junction, the more eastern locality from which collections were made in Tennessee, and that at Wickliffe, the more northern one in Kentucky, each representing deposits that are typical of the Lagrange, are of the same age as those carrying the fossils described from Mississippi. These are generally regarded as belonging to the "Lignitic" and are consequently of Eocene age.

The beds at Columbus and Hickman are undoubtedly in the upper part of the Lagrange formation as defined here. Whether they are both of the same age, and also whether they may be correlated with the clays just beneath the Lafayette at Memphis or are older or younger, can not be determined from the data at hand. Lithologically the Columbus beds are not distinguishable from other exposures of typical Lagrange deposits, but they differ in appearance from the beds at Hickman, and if the two are of different age the Columbus beds are probably slightly older.

Loughridge[a] thought the Hickman beds to be the oldest Eocene deposits in Kentucky and placed them provisionally as a distinct group—the Hickman—beneath the Porters Creek, though he recognized and stated that their exact position with reference to the other divisions of the Eocene had not been positively ascertained. From a study of their field relations and of well sections made since Loughridge's work was done there can be no doubt that the Hickman beds are younger than the main body of the Lagrange, and are among the youngest of the pre-Lafayette deposits of the region.

The question then arises whether they are of the same age as the rest of the Lagrange beneath, or whether there is an unconformity in the Lagrange as here defined and the upper part should be separated and regarded as of distinctly later age. There is not at present sufficient stratigraphic evidence for such a separation, but the character of the plants would seem to favor it and it may be established by more detailed stratigraphic work and additional confirmatory paleobotanical evidence, so that the Hickman deposits

[a] Loughridge, R. H., Jackson Purchase Region, 1888, p. 37.

and other beds similarly situated along the Mississippi bluff, including perhaps the 200 feet of clay at Memphis, would be assigned to the Miocene or Pliocene.

Following the example of Safford in recording his belief as to the age of the leaf beds near Lagrange,[a] and that of Knowlton in the report given on pages 38–39, in speaking of the age of the Wickliffe and Grand Junction beds, the writer can not refrain from also recording his impression that these upper Lagrange beds are not of Pliocene age but belong to the Lignitic, and so are Eocene, though he recognizes that this is but an impression gained during field studies and that the evidence of the plants would seem to be against it. Until conclusive evidence is obtained for one view or the other it seems best to include the deposits in question in the Lagrange.

Nomenclature.—The terms Orange sand and Lagrange have both been applied by Safford to these deposits. So much confusion has arisen from the different usages of the term Orange sand by different geologists that by common consent it has been discarded.[b]

Thickness.—In the deep well at Memphis the Lagrange is 963 feet thick. The well at Dyersburg penetrated 678 feet of it and one at Hickman 750 feet without in either case reaching its base. In the Jackson well, near the eastern edge of the formation, its base was reached at a depth of 160 feet. At Wickliffe it is 430 feet thick and at Cairo 325 feet. The base of the formation dips from the margin of the deposit toward the center of the basin at from 22 to 27 feet per mile.

PLIOCENE SERIES.

LAFAYETTE FORMATION.

Extent.—Over all the above-described formations of the embayment region, and extending for miles farther eastward over the adjoining Paleozoic rocks, there is a thin blanket of sand and gravel that averages not over 20 feet in thickness, but may in places thicken to 40 feet or more.

This blanket is unbroken over much of the area, especially in the more level region away from the streams. The main streams have generally cut through and removed it, but in ascending the sides of their valleys one usually crosses the outcrop of the Lafayette before reaching the general upland surface.

In certain areas, however, it has been largely removed by erosion. Such areas are generally those containing the outcrop of one of the relatively impervious clay formations already described, such as the Selma clay or the Porters Creek, while the more pervious sandy formations on either side retain their Lafayette capping, only

[a] Safford, J. M., Geology of Tennessee, 1869, p. 426.

[b] See Hilgard, E. W., and Safford, J. M., Orange sand, Lagrange, and Appomattox: Am. Geologist, vol. 8, 1891, pp. 129–131.

slightly affected by erosion. An explanation of this selective removal has already been given (p. 17).

In Illinois the Lafayette is revealed beneath the loess in the deeper ravines and road and railway cuts and in the upland portions of Massac and Pulaski counties. Round Knob, 5½ miles north of Metropolis, in secs. 11 and 12, T. 15 S., R. 4 E., is capped by Lafayette ironstone conglomerate, 4 or 5 feet being visible. The deeper cuts on the Big Four Railroad near New Grand Chain station show Lafayette gravel under the loess, and the highways at intervals cut into it. The cut on the Illinois Central Railroad in the southern edge of Villa Ridge shows, beneath 15 to 20 feet of loess, 15 feet of Lafayette gravel resting on sands that may be of Cretaceous age. No effort was made to trace the Lafayette to the north beyond the edge of the embayment deposit, so that its northward extent in Illinois, just as its eastward extent in Tennessee, was not determined.

It has not been possible in the time devoted to this work to attempt to discriminate in detail the areas in which the formation is mainly absent from those in which it is present. Even in areas where it is predominantly absent small scattered remnants of it are often found. On the geologic map (Pl. I, p. 26) it is represented as a surficial deposit covering the entire area.

Character.—The sand which makes the larger part of the formation is usually orange or brick red in color and is often case-hardened and massive. Locally it is cemented by ferruginous matter into a firm red or rusty-brown sandstone and, instead of being massive and structureless, is distinctly stratified or cross-bedded.

The sands are often accompanied by gravels, which usually form the basal part of the formation, though locally they may occur in any part of the sand as narrow bands or be scattered irregularly through it. These gravels are especially prominent near Tennessee, Ohio, and Mississippi rivers. At many places along or near these streams the formation consists solely of a thick gravel bed. Away from these streams, as a rule, the amount of gravel is much less and the average size is smaller, showing very plainly that the streams have had an important influence in determining the distribution of the gravel.

The gravel phase is somewhat prominent in the region just west of Tennessee River, though there is apparently a decrease in the average size of the gravel as one goes downstream. The gravel in the Lafayette of Hardin County, Tenn., for instance, is coarser than that in Calloway County, Ky. The gravel pit on the Shiloh National Park road just south of Snake Creek shows 15 feet of well-rounded gravel that averages from 1 inch to 2 inches in diameter, though much of it is 3 inches and an occasional piece reaches 12 inches. Most of this deposit is chert stained yellow by iron, but

there are some pieces of sandstone, quartzite, and vein quartz, and a piece of dark-purplish porphyry containing red jasper was seen.

At Memphis the gravel is well rounded and almost entirely of chert. The thickness of the bed varies from a feather edge up to 45 or 50 feet. At Columbus, Ky., the Lafayette is 45 feet thick, the lower 20 feet consisting of yellow chert gravel with average maximum diameters of 1 inch to 1½ inches, but with a 4-inch layer of 3 to 4 inch pebbles. The upper 15 feet consist of a clayey sand at the base, grading into a gravel bed in the upper part. A few of the smaller and best rounded pebbles are of vein quartz, but a very careful search here and at other places along the Mississippi failed to reveal any pebbles of granitic or other crystalline rocks that might have had a northern origin.

Where the Lafayette contains an abundance of gravel the line of unconformity at its base is easily recognized, but where gravel is absent and the formation consists of materials very similar to those of the underlying beds and probably formed from them by a slight reworking it becomes a matter often of much difficulty to determine the contact.

While variations of material occur in the Lafayette, not only in different sections but even in the same section, the formation can not be divided, at least in the area under consideration, into two or more members, but must be regarded as a unit one of whose prominent characteristics is its variability. Its composition at any one place is at once a result and an index of the underlying materials from which it has principally been derived, the greatest exception to this rule being in those areas where the larger streams have added to it their tribute of foreign gravel.

Thickness.—It has already been stated in the discussion of the Lagrange section (p. 36) that of McGee's three divisions of the Lafayette only the uppermost is really Lafayette, while the lower two are Lagrange. Nowhere in the region is there evidence that the Lafayette reaches any notable thickness. If it is anywhere 50 feet thick it is exceptional, while half this amount, or even less, would be nearer the average.

The Lafayette usually contains an abundance of ferruginous matter, which gives it the deep-red color so characteristic of the formation and which in many places has cemented the gravels into an ironstone conglomerate that, where erosion has been especially vigorous, may be seen in remnants capping the hills, while blocks from the undermined portions strew their sides. In some places the sands are similarly cemented into a red sandstone. Where the gravel is loose, as is more commonly the case, the ferruginous matter is usually present in large quantities and makes the Lafayette gravel a most excellent road-building material by binding it together, so that it soon packs into a firm, hard road. Often a thin shell or plate of ironstone makes

the very base of the Lafayette, and in some cases is thick enough to prevent the downward passage of percolating waters and thus form a local impervious stratum above which the sands may be saturated with water, while the underlying sands may be practically dry.

Ironstone conglomerate.—From inequalities of elevation of the basal impervious layer the water above it may be in small basins separated by areas where wells would fail to find water and two neighboring basins might not have water at the same level. If the impervious bottom of one of these be dug through, the water in it at once drains downward into the dry sand below. These relationships are shown graphically in fig. 5.

Section at Ripley, Tenn.—In the center of the deep railway cut at Ripley, Tenn. (Pl. III, *B*), Lagrange sands and clays extend up 25 feet, but disappear beneath track level toward each end of the cut. On the crest of the hill of Lagrange material thus revealed there are 4 or 5 feet of red case-hardened Lafayette sand that thickens on the flanks of the hill to 8 or 10 feet near the end of the cut. Over this sand in the center of the cut are 4 feet of gravel in soft, loose, light-colored sand which grades up into a dark-colored, damp, clayey loess 10 feet thick, overlain by a light-colored, dryer, more pulverulent loess 18 feet thick. At many points in the cut it is impossible to be sure of the existence of a line of unconformity between the Lafayette and the underlying Lagrange sands. The soft light-colored sand and gravel between the Lafayette and the loess belong to the Columbia (as does the loess) and are referred to again in the discussion of that formation (pp. 44, 46).

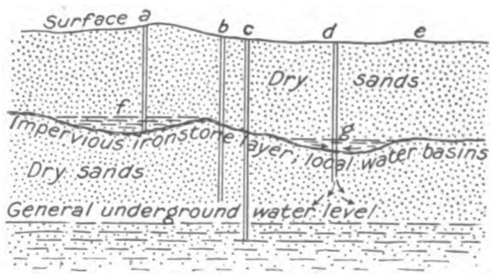


FIG. 5.—Diagram showing local water-bearing basins at various levels above dry sand. Well *a* obtains water from a local water-bearing basin at *f*. Well *d* struck a similar but slightly deeper local basin, but pierced the underlying impervious layer and allowed the basin to be drained downward. The well was abandoned before permanent water was reached. Wells *b* and *c* failed to find water at either the *f* or the *g* level; *b* was abandoned as a dry hole; *c* was continued slightly farther to permanent water level. Basins like *g* are sometimes drained by fissures caused by earthquakes in this region.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

COLUMBIA FORMATION.

Three kinds of deposits in this region will be grouped together under the Columbia formation. The first and oldest is a loose sand which overlies the Lafayette and underlies the loess, which is the second of the deposits here included. The third is a loam that overlies the loess in the area where the latter is found and extends east of that area for miles as a thin mantle spread over the Lafayette.

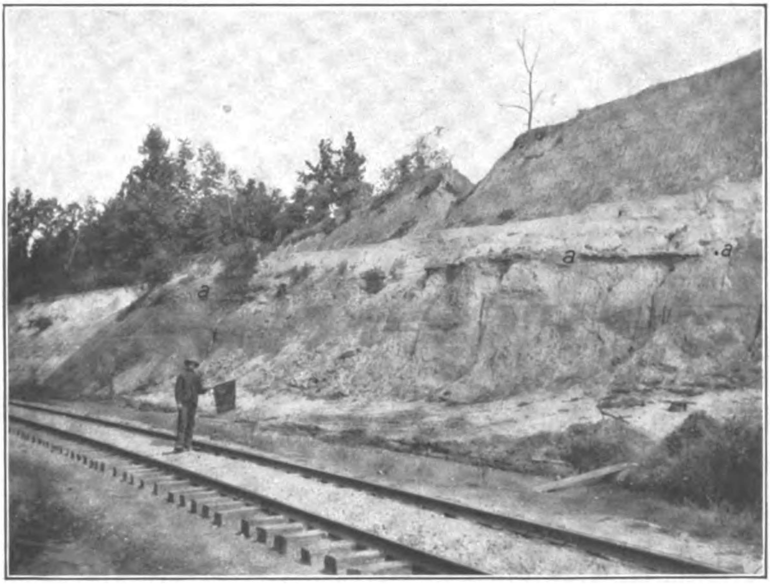
Sands.—At some places along the Mississippi bluffs and in a belt 10 to 20 miles wide east of the bluffs the loess seems to rest unconformably directly on the Lafayette sands or gravels. At other places, however, there is a distinctly differentiated bed of soft, loose, light-colored sand between the two. This sand often contains rounded pebbles similar to those of the Lafayette beneath, from which they have evidently been derived. Like the sand, which may also have originated from the Lafayette, the pebbles are usually bleached to a light gray. This difference in color and the softness of the sand serve to differentiate the deposit at once from the red, case-hardened Lafayette beneath. This sand may range in thickness up usually to 4 or 5 and exceptionally to 10 or 12 feet, and may attain its maximum and disappear again in 100 or 200 yards.

It commonly though not everywhere shows distinct unconformity on the Lafayette beneath and as a rule seems to grade upward into the lower, darker part of the loess without any perceptible break. Where the sand seems to be absent, the lowest part of the loess is usually somewhat sandy and may contain a small pebble here and there for several feet upward from its base. It is likely that in such cases the sandy basal part of the loess is the representative of the sand found elsewhere.

In the railway cut at Ripley, Tenn., a section of which is given on page 43, the soft sand and gravel over the Lafayette is usually sharply limited below, but in a few places seems to grade into the Lafayette. Near the ends of the cut the gravel in it practically disappears. Another excellent exposure of this sand is found some miles north of Ripley in the deep railway cut at Curve, Tenn., where the Lafayette is overlain by a soft, light-colored, loose sand with gravel that varies from a knife-edge to 3 feet in thickness and grades up into a dark silty loess. A view of this cut is given in Pl. IV, *A*.

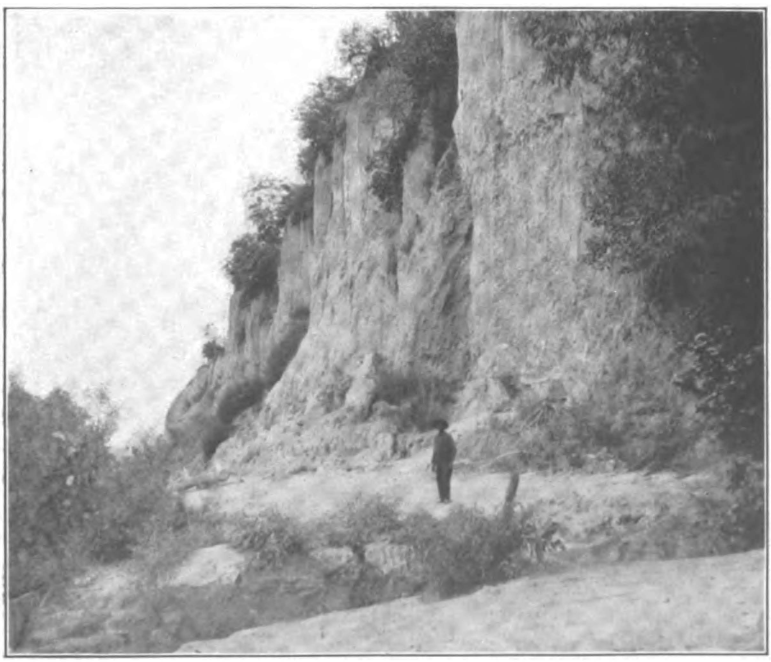
It seems very probable that this bed of soft sand and gravel is not confined to the narrow belt in which the loess occurs, but extends eastward over much of the region in which later deposits overlie the Lafayette, as the section at Mayfield (p. 135) shows the presence of such a layer between the Lafayette gravel and the surface loam, and similar conditions were seen at other places. In many exposures, however, such differentiation of the material over the Lafayette in the middle and eastern parts of the area can not be satisfactorily made. Either this basal sand and gravel phase of the Columbia disappears in places, or, as is thought more probable, it merges by change of material into the loamy phase, so that where the two are found together because of the absence of the loess which separates them along the Mississippi bluffs they are blended into a unit.

Loess.—This member extends eastward 20 to 30 miles from the edge of the bluffs overlooking the Mississippi bottoms. In the bluffs



A. CUT AT CURVE, TENN.

Showing at "a" local ironstone hardpan at base of Lafayette, resting on Lagrange.



B. LOESS BLUFF AT MEMPHIS, TENN.

it is usually between 50 and 75 feet thick, but locally exceeds or falls short of those figures. It is reported to reach a thickness of 200 feet in places in western Tennessee, but the writer has never seen it quite as much as 100 feet thick. From its maximum thickness along the Mississippi bluffs, as given above, the loess thins eastward to a feather-edge before it disappears. This thinning renders it difficult to fix any but a somewhat arbitrary line to mark its eastern edge, and the difficulty is enhanced by the fact that in some sections, instead of thinning out, it appears to grade over into the loamy phase of the Columbia.

As seen in a number of excellent sections, the loess is composed of a lower dark part and an upper lighter one. The lower part seems to be denser or less porous than the upper. It contains more clay and will remain damp longer. The clay is so abundant in many sections that the material is easily plastic when damp, and on drying it shows in places a tendency to shrink and crack open. More usually, however, this lower part presents when dry the same general appearance as the upper part, except that it preserves the darker color. In weathering the lower part disintegrates and wears back less rapidly than the upper part, so that in places a shoulder or change of slope is developed where the two divisions meet. This was well shown in the deep railway cut at Ripley, Tenn., before the recent widening was done in double tracking the line. The darker, more silty portion of the loess, which seems to grade down into the sand and clay member, as already mentioned, is quite distinct from the upper part. The same distinction is to be seen in the cut at Curve, Tenn. At Memphis (Pl. IV, *B*), Randolph, and elsewhere the same bipartite character is shown by the loess. The upper part is the typical porous, open-textured, light, ashen-colored loess. In it and the lower, darker portion alike are found the usual calcareous concretions, small, irregular in their distribution, and many of them curiously shaped.

In each case observed the lower portion is thinner than the upper and the line between the two is horizontal and distinct. It may be questioned, however, whether this line represents a rapid transition without interruption in the deposition of the loess or, as is claimed by some, is indicative of an actual break in the process and represents a time interval between two periods of loess formation. Without wishing to express a decided opinion on the subject until he has had opportunity for further and more detailed study, the writer is inclined to the former view and would provisionally regard the loess in the area here considered as the product of one period of deposition rather than two.

Over much of the first tier of counties east of Mississippi River in Tennessee and Kentucky the loess averages 30 feet in thickness. It

accordingly conceals the Lafayette except in an occasional stream cutting. In southern Illinois practically all of the upland area in which embayment deposits occur is overspread with a sheet of loess, usually a score or more feet in thickness.

The exact mode of formation of loess deposits has been a matter of much discussion and difference of opinion, but all are agreed that the material of the loess is the finely ground rock flour resulting from glacial erosion. The loess of the Mississippi Valley owes its origin to the great ice sheet that covered all of the northern part of the valley and extended in southern Illinois to within 20 miles of the head of the embayment deposits. There are differences of opinion, however, in regard to the manner of deposition of the material. Some insist that it has been transported and deposited by the wind. Others believe it has been transported by streams and deposited in water either on a flood plain or in the bottom of a lake—that it is fluviatile or lacustrine instead of eolian.

Without entering into a detailed discussion of the evidence for the conclusion here stated, the writer may state his belief that the loess of the region under consideration is of fluviatile and not of eolian origin. The grading upward of the sands and gravels into the loess, the local occurrence in the loess of sandy streaks that must have been water-laid, the bipartite division of the loess seen widely over the region, the regularity or evenness of the contact plane between the two parts, and the absence of wind-deposit structure all give basis for the opinion here expressed as to the mode of deposition.

Loam.—The third phase of the Columbia formation in this region is a yellowish or brownish loam in most of the area of its occurrence, though in some places it becomes a soft sand with very little argillaceous material. This phase is found mainly to the east of the area of the loess and is to be regarded as largely the equivalent of that member, though in some places in the loess area a few feet of loam overlie the loess.

The loose sand at the base of the Columbia blends with the overlying loam east of the loess area just as it grades up into the loess where the latter overlies it. In some places the blended sand and loam may be rather sandy, while in others they may grade into a clay. The best example of the sandy phase is found at Lagrange, Tenn., where the Lafayette is overlain by a layer of black soil a foot thick, and that by 15 feet or more of soft, light-colored, cross-bedded sand. This was the only locality in the entire region where a soil layer was found between the Lafayette and the Columbia. A similar soil layer was found by McGee at Holly Springs, Miss.[a] The appearance of the soil layer and the overlying sand at Lagrange, considered in connection with its peculiar topographic relationships,

[a] McGee, W J, The Lafayette formation: Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, p. 460.

suggests very strongly that the cross-bedded sand over the soil may be a local wind-made deposit of recent origin rather than a part of the Columbia. It caps the southward-facing scarp that overlooks Wolf River. The steep slope down to the river is cut by many deep ravines whose bare sides are of soft, loose Lagrange sand. It is conceivable that the strong winds from the south blowing up the ravines might catch up the loose sand and carry it to the top of the scarp in such quantities as to account for the cross-bedded sands found there over the soil layer. The ascending sand-bearing air current would, on reaching the top of the scarp, produce an eddy in which the sand would be dropped, as is illustrated in fig. 6.

Although the writer has not seen the Holly Springs occurrence referred to above, yet McGee's statement that the topographic relationships are exactly similar to those at Lagrange is highly suggestive of a similar eolian origin for the sand there found over the soil layer.

The Columbia loam, east of the loess, is a thin veneer derived from the Lafayette and resting upon and partly concealing it. It is rarely over 10 or 12 feet thick and is often not more than half that thickness. It thins out to the east, and in Tennessee and Kentucky disappears before the eastern edge of the embayment deposits have been reached. In Illinois the loess makes the surface of the uplands of the embayment region, and the loam seems to be absent. It has not been found practicable to represent on the geologic map the area covered by the Columbia loam. In a general way its eastern edge crosses eastern Hardeman, eastern Madison, western Carroll, and western Henry counties in Tennessee, and western Calloway and western Marshall counties in Kentucky.

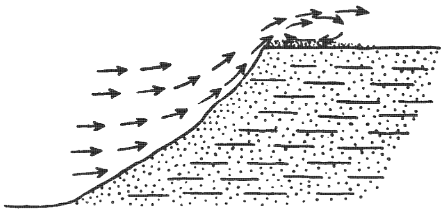


FIG. 6.—Section showing sand deposited in eddy of wind current on top of bluff.

RECENT DEPOSITS.

Alluvium.—Between Mississippi River and the bluffs that bound its valley on the east there is a varying width of flood plain composed of alluvial deposits. At a few points in Tennessee and Kentucky the river swings against the bluffs on its eastern side, but usually the alluvial plain is from 2 or 3 to 8 or 10 miles wide. In Illinois the Mississippi alluvial plain is a number of miles wide and the flood plain of the Ohio is of similar character, though it is mostly confined to the Kentucky side of the river. The main tributaries of the Mississippi, such as the Hatchie, the Forked Deer, and the Obion, have similar valleys composed of alluvial deposits and varying from 1 mile to several miles in width.

The materials composing these plains are sands and silts brought down by the rivers and deposited in time of flood, thus building up flood plains in the valleys which the rivers had previously carved out of the older formations of the region.

No extensive study of the alluvium was made, for want of time, but where examined in a number of places the silts seemed all to be of modern origin and the writer would assign the deposits seen at Memphis, those along the banks of the river from Memphis to Fulton, Tenn., those at Hickman, at Columbus, at Wickliffe, at Cairo, and at Paducah to the recent period. When it is considered how constantly and, as a rule, how rapidly Mississippi River is shifting the position of its channel because of meandering, and when it is further considered not only how each meander grows until the meander belt is a number of miles wide, but also how each meander is slowly working downstream, cutting away the materials before it while other materials are being deposited behind it, it may be concluded that nowhere near the river can any deposit in the flood plain remain long unmoved if it rises above the level to which the river can cut—a level which may be taken as about 100 feet beneath the flood-plain surface. Instances are innumerable of the cutting away of flood-plain deposits on one side and rebuilding on the other by the lateral swing of the river. It is, in fact, going on all the time, as the surveys of the Mississippi River Commission show. The entire channel may move a mile or more by such cutting in a few years, and the changes that have occurred within the memory of men yet living are so great that it is not improbable that the river may have swung entirely across its valley from Crowleys Ridge in Missouri and Arkansas to the Chickasaw and Columbus bluffs in Tennessee and Kentucky in 2,000 to 4,000 years.

That these alluvial deposits are geologically young is apparent from another line of reasoning. They have been deposited in a valley that is 30 miles wide at Memphis and 45 miles wide farther north. This valley has been cut at least 200 to 300 feet beneath the plain in which it is carved. The dissevered portions of this plain are seen to-day in the flat upland surface of the bluffs on the east and of Crowleys Ridge on the west. This surface, however, is capped with the loess and the excavation of the broad valley has mainly taken place since the loess was deposited. There was some cutting away of the Lafayette along the main Mississippi River before the loess was deposited, corresponding to the cutting on the tributaries of the Mississippi to form the second bottoms, where the Lafayette has been removed but the loess is present; but this cutting was not sufficient to account for the excavation of the valley as we now find it. Since the excavation was finished some alluvial filling has occurred, leaving the level of the flood plain as at present.

From borings made by the Mississippi River Commission it is

concluded that in the portion of its valley from Cairo to Memphis the river has not cut into the embayment deposits more than between 100 and 150 feet beneath its present flood-plain surface, or in other words, has never cut very much deeper than its channel may now reach under favorable conditions for deep scouring.

These alluvial deposits are accordingly believed to be between 100 and 200 feet thick and of later age than the loess; parts of them, of course, are still forming. Near the river the deposits are sands and silts; farther away from the river they become gradually finer and pass into clays which are usually blue or dark colored from the organic matter present.

The same uplift which permitted the Mississippi to cut out so broad a valley in the loess-sheeted plain likewise permitted its tributaries to incise their courses beneath the uplands and to broaden their valleys until they were locally 5 to 10 miles wide. The alluvial deposits in the valleys of these tributaries are like those of the Mississippi and consist of silts and sands that usually contain much decaying vegetable matter. It is generally the rule that since the formation of these alluvial deposits by the tributaries of the Mississippi they have been cut into and another flood plain has been formed 10 to 15 or occasionally as much as 30 feet lower than the older alluvial surface. This older surface is known as the "second bottoms," while the lower plain is the present-day flood plain, large portions of which are swampy. It is surprising to note how characteristic a feature of the region these first and second bottoms are. They are found even along the smaller headwater streams in many places. The present flood plain, or first bottom, is usually much narrower than the second bottom.

The writer has been thus explicit in giving his conception of the very recent age of the alluvial deposits of the Mississippi in this region because various authors[a] have correlated parts, at least, of these deposits, from Memphis up as far, in one case, as Paducah, Ky., with the Port Hudson deposits of Mississippi. The stratigraphic position of the Port Hudson clay is between the Lafayette gravels beneath and the loess above. Since the valley in the region here considered was not excavated until after the loess had been deposited the clays found in this valley, at least from Memphis up, can not be older than the loess and so can not be of Port Hudson age.

The lithologic similarity of the Port Hudson clay and certain blue clays found in this region, notably about New Madrid, Mo., is only what might be expected. Both were formed by the same agency. Similar materials under these circumstances should form similar deposits whether they be of Port Hudson or of younger age.

[a] See McGee, W J, The Lafayette formation: Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, p. 400; Loughridge, R. H., Jackson Purchase Region, 1888, p. 74; Shepard, E. M., The New Madrid earthquake: Jour. Geol., 1905, p. 48.

GEOLOGIC STRUCTURE.

In discussing artesian conditions in the region and in describing the area of outcrop and dip of the various formations, much has already been said concerning the structure of the embayment deposits. Only a brief recapitulation is necessary here. It has already been stated that these deposits lie in the eastern half of a broad basin projecting northward from the Gulf region and ending in southern Illinois. On the floor of this basin the formations described in previous pages were laid down in succession in broad sheets one above another. The eastern edge of each formation in Tennessee and Kentucky usually does not overlap the edge of the formation beneath, but permits its exposure in an outcrop of varying width which extends northward across these two States. At the north end of the trough in southern Illinois the formations rise to the surface like the tip of a spoon. The western half of the basin lies in southwestern Missouri and eastern Arkansas.

It does not seem probable that the floor of this basin slopes at all uniformly from its outcropping edges to a deepest central line, but rather that the slope is relatively rapid near the sides of the trough and decreases farther out in it, or that a cross section of the trough is broadly U-shaped rather than broadly V-shaped. If so, as each of the formations that fill the trough is probably nearly uniform in its thickness, the dips are steeper near the margins of the trough than well out within it. Ascertained dips for short distances near the margins are about 30 feet per mile, while some of the data reported for southern Illinois would, if correct, indicate southward dips there of about 50 feet per mile. Well within the basin westward dips of 22 feet per mile are found.

There are no indications of any folding of the rocks of the embayment, but in the Porters Creek formation there has been in many places a slight faulting accompanying the earthquake disturbances that have caused the formation of the sandstone dikes described on page 30. In the Reelfoot Lake region the Lagrange sands were fissured and in places slightly faulted by the New Madrid earthquake of 1811–12. The vertical displacement seems, however, in no case to have exceeded a few feet. This faulting in the Porters Creek and the Lagrange has not materially affected the water-supply problems of the region here discussed. There seems to be no evidence, in this region, at least, that the artesian pressure has been decreased because the earthquake fissures provided channels for the water to escape. The approximate elevation to which artesian waters rise in various parts of the region is given for a number of places on page 160 and graphically represented in fig. 13. From this it is readily seen that

Dyersburg and Union City, Tenn., and Hickman, Ky., the nearest localities given to the earthquake center, do not show any abnormal depression of hydrostatic level when compared with other places near by.

UNDERGROUND-WATER RESOURCES.

RESOURCES OF TENNESSEE, BY COUNTIES.

BENTON COUNTY.

Topography.—Benton is a long, narrow, county, lying just west of Tennessee River and extending north and south along the river for a distance of 40 miles. Its north end, which almost reaches the Kentucky line, is formed by the junction of Big Sandy and Tennessee rivers. The Big Sandy, which flows northward almost parallel to the Tennessee, forms its northern and about half of its western boundary. The area of the county, as given by the Twelfth Census (1900), is 430 square miles. The surface is best described as being rolling to hilly. Very little of it is level, owing to the proximity of Tennessee and Big Sandy rivers, whose numerous small tributaries have cut the originally level surface into hills near the rivers and made it rolling farther away from them. The streams are usually bordered by a flood plain and a second bottom which varies from a few hundred yards to half a mile in width.

The maximum elevation in the county is found along the ridge separating the Big Sandy and Tennessee river watersheds. This ridge attains heights of 500 to 600 feet above tide. The lowest point in the county is at the Big Sandy, where the elevation at low water is about 310 feet. Low water at Johnsonville is 322 feet. The elevation at Big Sandy station is 347 feet, at Camden 444 feet, and of the

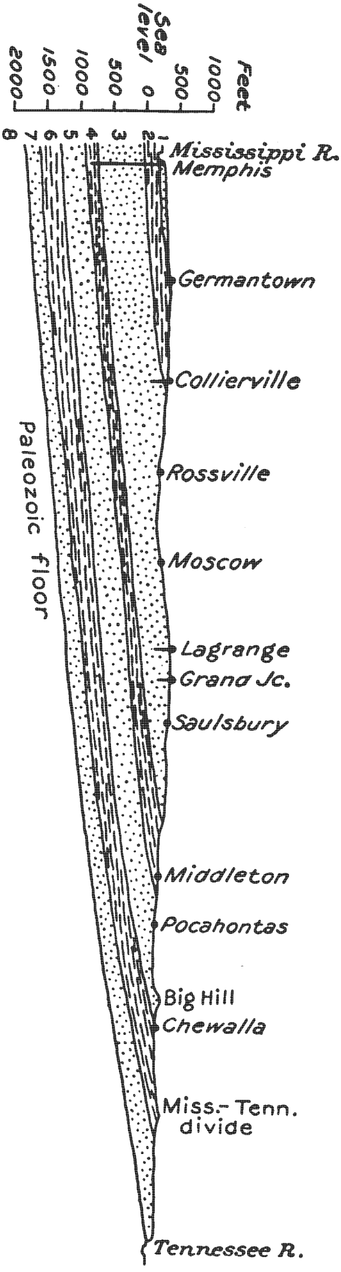


Fig. 7.—Section from Tennessee River westward to Memphis, Tenn. 1, Loess; 2, clay member of Lagrange; 3, sandy member of Lagrange; 4, Porters Creek clay; 5, Ripley sand; 6, Selma clay; 7, Eutaw sand; 8, Paleozoic floor.

summit just west of Camden, on the Nashville, Chattanooga and St. Louis Railway, 486 feet. The average elevation of the county is between 400 and 450 feet. As it is on the eastern border of the embayment region, where the outcrop of the porous Ripley strata receives its water, very little artesian pressure could be expected anywhere in the county. Some wells on the flood plain of the Big Sandy, however, flow with a slight head.

Geology.—The contact between the Paleozoic limestones, shales, and cherts and the embayment deposits runs north and south through about the middle of the county. The eastern half of the county lies accordingly in the Paleozoic area, and will not be discussed here. The rocks of the western half are of Cretaceous and Pliocene age.

The Eutaw sand extends for a few miles northward into the south end of the county, but its area is small and its thickness can not be very great, owing to its relation to the Tennessee River drainage and to the fact that it feathers out here and disappears, not being found farther north. Water issues from the base of the Eutaw in springs along the hillsides in numerous places and is reached at from 20 to 40 feet in wells. It is chalybeate in places where there is much lignitic material in the formation.

It is probable that just west of the Eutaw area, in the extreme southwestern part of the county, there is along Birdsong Creek a small area of the Selma clay, though, owing to the topography, exposures are poor and the delimitation of the north end of the Selma outcrop has not been definitely made. The water in this formation is small in amount and of very poor quality. The Selma area in this county is so small as to be practically negligible.

The Ripley sand covers the western part of the county. Its eastern edge extends from the southwest corner of the county northward past Camden, and the formation embraces part of the divide between the Big Sandy and the Tennessee, extending probably as far north as the Louisville and Nashville Railroad before thinning out and disappearing. For some distance in its lower course the Big Sandy has cut through the Ripley sand into the underlying Paleozoic rocks. The Ripley furnishes abundant supplies of good water, but owing to its open, porous texture the depth of wells in this formation is greater than elsewhere, ranging from 60 to 100 feet or more. Springs are not so abundant in it as in other formations.

Overlying these Cretaceous formations and the Paleozoic rocks is a blanket of Lafayette sand, loam, and gravel that is tattered by erosion along the larger streams, but mantles the inter-stream areas in an unbroken sheet from 10 to 30 feet or more thick. In many places the formation contains limonitic iron ore in considerable quantities. In places springs issue from the base of the Lafayette,

though they are usually weak and their flow may decrease or fail during long droughts.

Water resources.—Benton County is naturally well watered by streams that flow the year round and furnish abundant water for stock. Along the base of the hills numerous springs are found. In the embayment area these come mostly from the Lafayette or the Ripley, the latter furnishing the larger number and the stronger flows. Springs and wells usually yield soft, freestone water, but in a few cases it contains sulphur and iron. Domestic supplies are derived from springs and open wells, the latter being somewhat the more important source. These wells may be as shallow as 10 feet in low ground along streams or as deep as 100 feet on high ground in the Ripley sands. Very few cisterns are in use.

At Big Sandy station, elevation 372 feet, the principal water supply is derived from wells which range from 6 to 50 feet in depth and yield an abundance of soft water from gravel which underlies a clay bed 4 to 6 feet thick. Springs also are much used, and there are a few cisterns.

At Bristow open wells of moderate depth are exclusively used.

At Faxon springs and open wells 25 to 30 feet deep furnish the supply.

Gismonda is very near the edge of the Paleozoic area, and a number of sulphur and chalybeate springs flow from sands.

At Nobles the supply is derived from the Ripley sands by small bored wells that range from 60 to 125 feet in depth.

At Wyly there is a flowing well located 6 feet above high water on the Big Sandy. It is 1½ inches in diameter, 50 feet deep, and yields 5,000 gallons a day. The flow varies somewhat at times. Other wells are mostly open, are on higher ground, and furnish soft water at a depth of 25 to 30 feet.

At Zach the country is flat, and wells are from 10 to 20 feet deep. There are a few springs, but in summer their water is not cold.

CARROLL COUNTY.

Topography.—Carroll County is situated in the northeastern part of western Tennessee. For 2 miles on the northwest South Fork of Obion River separates it from Weakley County. Its area is 624 square miles.

The watershed between Mississippi and Tennessee rivers crosses the county in a direction somewhat east of north and separates it into an eastern slope which embraces about a third of the county and drains into Big Sandy and Tennessee rivers, and a western slope which embraces the rest of the county and drains into the Mississippi. The highest part of the county is along this divide, which has an

elevation of from 450 to nearly or quite 500 feet. The lowest elevation is about 350 feet, at the points where the Big Sandy and South Fork of the Obion leave the county. The average elevation of the county is not far from 425 feet. The surface along the Tennessee-Mississippi divide is hilly and broken, for headwater erosion is active. The northern and western parts of the county are more level and the main streams here, as a rule, have broad, level flood plains and second bottoms.

Geology.—The Selma clay occurs in the extreme southeast corner of the county, but covers a very small area. West of it there is a belt of Ripley sand 6 to 8 miles in width that occupies the eastern part of the county, its western edge running about parallel with and 2 miles west of Big Sandy River. Along the broad valley of the Big Sandy water is found in the Ripley sand at slight depths, but on the uplands wells average from 50 to 125 feet in depth and furnish soft water.

West of the Ripley sands there is a belt of Porters Creek clay about 2 miles wide, its western edge passing through Huntington. This clay is popularly known as soapstone. It is variable in thickness, being in some wells only 10 feet thick, while in others it is 80 feet or more. In many places it is almost black and imparts a disagreeable odor to the water. Physicians report that people habitually using such water become pale, anæmic, and sickly. If the Porters Creek is everywhere less than 100 feet thick in this county, as it seems to be wherever records of its thickness have been obtained, it should always be possible to go through it and get good water from the underlying Ripley sands. To the west the Porters Creek dips under the Lagrange sand at a low angle and may be reached, in low places especially, in wells dug within half a mile or a mile west of its surface outcrop. Such wells should either be dug on through it to the Ripley sand or be stopped just above it, so as to draw water from the basal sands of the overlying Lagrange.

West of the Porters Creek clay belt the county is underlain by Lagrange sands and clays. The sands are soft and variable in texture so that coarse beds are not widely continuous, but occur at various horizons and extend each usually over a small area only. With the sands are thin beds of plastic clays, and locally these beds serve to confine the waters in the underlying sand. When such clay strata are dug or bored through the water often rises at once a number of feet, dependent on the local elevation. In low places, as along the bottoms of the streams in the western part of the county, artesian flows may be obtained. There are a number of such artesian wells less than 100 feet deep in the bottoms just west of Huntington. On the rolling uplands of the western part of the county the Lagrange

yields water at depths of 35 to 100 feet. The water is always soft, but may in places contain iron and sulphur. Bold springs may rise from the Lagrange sands in the bottom lands along the streams, while out on the edges of the valleys, along the foot or on the slopes of the bordering hills, weaker springs issue from the base of the Lafayette.

Over the formations already named there is a covering of 10 to 20 feet of Lafayette sand and sandy clay. Occasionally there is a little gravel in the lower part, but as a rule gravel is inconspicuous or absent. In the western part of the county a few feet of Columbia loam overlie the Lafayette.

Water resources.—The streams of Carroll County are numerous enough to furnish a supply of running water for stock almost everywhere. These streams flow the year round. For household supplies open dug wells are much in use where water may be obtained at such moderate depths as 25 to 50 feet. Even for these depths, however, bored wells have been in recent years largely used instead of the olden-time dug wells, because they are easier to make and cheaper. Bored wells are also in use where it is necessary to go 50 to 100 feet or more, though for depths of 100 to 150 feet small pipe wells sunk by a hydraulic jet are common. The bored wells run from 4 to 12 inches in diameter and are curbed with wood. Water is usually drawn by a cylindrical bucket with a valve in the bottom. Some bored wells are curbed with terra-cotta pipe, and some of these, in in low places, where the ground-water level is nearly at the surface, overflow in spite of the loose joints of the terra-cotta—that is, they are artesian. The small-pipe wells are usually fitted with a force pump run by hand, wind, or steam power, the latter being used only where the well furnishes the boiler supply for a cotton gin, sawmill, or other manufacturing establishment. In the belt underlain by the Porters Creek clay, where well water is almost unfit to use, and in the more elevated parts of the Ripley and Lagrange areas, where the depth to water is often 100 feet or more, many cisterns are in use. Deep waters may be obtained in the central and western parts of the county from either the Lagrange or the Ripley sands. In the Lagrange it will probably nowhere be necessary to go deeper than 200 feet, and the water will rise to about 375 to 400 feet above the sea, the height decreasing westward. The water in the Ripley may be reached at depths of 250 to 300 feet from Huntington eastward; west of Huntington the Ripley sands lie deeper, and soon the Lagrange sands above become thick enough to furnish a deep-water supply. The few mineral springs in the county are sulphur or chalybeate and are of local note only.

At Atwood, elevation 439 feet, good pure water is found in

abundance in the Lagrange sands at depths of 65 to 90 feet on the higher ground. One record showed surface sands and clay 20 feet, sand 18 or 20 feet, potter's clay 8 feet, yellow sand 76 feet (with water at 90 feet), gravel 6 feet.

At Carnsville, near the eastern edge of the Porters Creek clay, there are some wells in this formation that yield water unfit for use on account of its astringent taste and bad odor. Others, 30 to 75 feet deep in the Ripley sands, furnish an abundance of good water.

At Cedar Grove, where the Lagrange sands outcrop, the water supply is derived from shallow wells and numerous springs. Three miles to the south there is a sulphur and iron spring of some local note. There are deep wells.

At Clarksburg good water is obtained from the Ripley sand at depths ranging from 20 feet on low ground to 135 feet on higher ground. At the shallower depths wells were formerly dug, but now nearly all are bored, the usual size being 12 inches. There are few pipe wells and very few springs.

At Dollar, also, water is obtained from the Ripley sand by means of bored wells, the average depth being from 50 to 135 feet, though some are only 20 feet. A few springs are in use.

At Garrettsburg, where the Ripley sand outcrops, shallow open wells and springs are used, the wells for domestic supply and the springs for stock.

At Hico, elevation 389 feet, an abundant of good soft water is obtained from the Lagrange sand at depths of 30 to 50 feet.

At Hollow Rock, elevation 425 feet, water is struck in open wells in the low, flat part of town at depths of 15 to 25 feet, and on higher ground at depths of 40 to 80 feet. A mile or two west of town, on the Mississippi-Tennessee divide, wells average 100 feet deep. All are in Ripley sand. There are numerous springs in low places along the streams, but the water is not considered healthful. In Hollow Rock a well, formerly 60 feet deep, but now filled up, is reported to have had an abundance of good water in the summer, but to have gone dry in the winter.

At Hollow Rock Junction, elevation 416 feet, the Nashville, Chattanooga and St. Louis Railway uses a small stream for supplying its engines.

Huntington, elevation 414 feet, is situated on the western edge of the Porters Creek clay. In some places the dark unctuous clay, or so-called "soapstone," is at or within a few feet of the surface and varies from 10 to 75 or 80 feet thick. At other places there are from 20 to 50 feet of Lagrange and Lafayette sands over the Porters Creek clay. Some shallow wells are in the Lagrange sand and have good water; others are in the "soapstone" and have poor water; while still others go through the "soapstone" and get good water from the

Ripley sand beneath. These open wells vary in depth from 10 feet in the bottoms just west of town to 90 feet on the town level. Wells sunk 50 to 70 feet in the bottoms usually flow at the surface with a head of 2 or 3 feet. Their water is soft, but usually contains some iron and sulphur; it is derived from the base of the Lagrange sand. There are two deep wells within 5 feet of each other at the Huntington corporation light and water works. They are 6-inch wells, drilled in 1898, one being 213 and the other 265 feet deep. The water rises a few inches above the surface. A log given from memory is as follows:

Log of well at Huntington, Tenn.

	Feet.
Sand and clay (Lafayette and Lagrange)	40
"Soapstone" (Porters Creek clay)	65–70
Gray sand, partly somewhat indurated (Ripley)	155–160

These two wells are said to be capable of yielding 800,000 gallons per day. An average amount of about 25,000 gallons per day is pumped into the mains under a direct pressure of 60 pounds for ordinary service, which is increased to 120 pounds for fire service. A chemical analysis shows the water to contain small quantities of iron and calcium carbonates; sulphates of potash, lime, soda, magnesia, and alumina; sodium and potassium chlorides, and sulphureted hydrogen. It is somewhat hard for washing, and the iron makes clothes and vessels yellow. It deposits in boilers only a rusty sediment that is easily blown off. The cold water eats out the valves and joints of pipes, but the hot water does not injure either fittings or boilers. This water is considered very healthy. It is reported that in five years no case of typhoid fever has developed in town where the deep-well water is used.

At Lankford there is a flowing well 6 inches in diameter and 100 feet deep. The water is used for household purposes, and is said to have medicinal qualities.

At Lavinia water is obtained at 160 feet depth, the entire section being sand.

At Leach water is obtained from springs and ordinary shallow open wells in the Lagrange sand.

At McKenzie, elevation 481 feet, some cisterns are used, and there are numerous wells ranging from 23 to 95 feet deep, the shallower ones being dug, the deeper ones bored. The shallow wells show some tendency to fail during dry seasons. There are also a number of deeper driven wells in the town and immediate vicinity that range from 175 to 335 feet deep. Water is abundant and soft in all of them. In some it contains iron, but not in objectionable quantity. These wells are generally used for boiler supply and stock watering on large farms. The Louisville and Nashville Railroad has a 6-inch well, reported by one person to be 335 and by another to be 362 feet deep.

The material encountered was chiefly sand. Water rises to within 90 feet of the surface.

At McLemoresville there are some springs, but water is obtained from dug and bored wells 40 to 50 feet deep that get water in the Lagrange sand. The water is reported hard in one, soft in others.

At Mixie there are small bored wells and good, strong springs.

At Muse a supply of fair to good water is obtained from the Ripley sand. Wells are about 50 feet deep; the flow is rather weak.

At Post there is a bored well 24 feet deep that flows. The water is from the Porters Creek clay, and contains iron and sulphur.

At Townes a supply of good water is obtained from springs and shallow, open wells in the Ripley sand.

At Yuma, elevation 480 feet, a water supply is derived from the Ripley sand by ordinary open wells that range in depth from 20 feet in low places to 100 feet on higher ground.

CHESTER COUNTY.

Topography.—Chester County is situated in the southeastern part of the area discussed in this paper. It is of irregular shape. The area of the county is 300 square miles, nine-tenths of which belongs to the Mississippi drainage basin, the remainder draining into Tennessee River. The Mississippi-Tennessee divide crosses the eastern part of the county. Along the water parting the surface is high and the country much broken and in places hilly and rough. The elevation along this summit ridge reaches nearly or quite 600 feet above tide. The eastward slope is steep and much cut up by the headwaters of the tributaries of the Tennessee. The slope to the west is at first steep and rough also, the surface being much dissected by the headwaters of Forked Deer River, but the middle and western parts of the county are more nearly level. Between the streams the general surface is flat, being broken only in a narrow fringe along either side of the main stream valleys, which lie 20 to 40 feet lower than the general country level. The average elevation is between 450 and 500 feet, the highest point being about 600 feet on the dividing ridge, as already stated, and the lowest about 370 feet on the level of Forked Deer River at the point where it leaves the county. The streams east of the divide are all small and are the headwater tributaries of White Oak River and of Piney Creek or Beech Creek. West of the divide Forked Deer River attains considerable size before it leaves the county. A small area in the southwestern part of the county is drained by the headwaters of Piney Creek, a tributary of Hatchee River.

Geology.—The rocks of Chester County consist of the Selma clay and Ripley formation of the Cretaceous, the Porters Creek and Lagrange of the Eocene, and the Lafayette of the Pliocene.

The upper half of the Selma clay underlies about 20 square miles of the east end of the county. It lies entirely in the drainage basin of White Oak River and its western boundary extends almost north and south. The fine clays of this formation are exposed in gullies and along the ravines draining into the headwaters of White Oak River. They are overlain by Lafayette gravels and clays in places on the uplands where erosion has not been especially vigorous. The formation dips westward under the Ripley sands, which cross the county in a belt about 10 miles wide, their eastern part forming the dividing ridge between the Tennessee and Mississippi drainages and their western edge extending through Henderson. The Lafayette covering conceals a larger proportion of the Ripley than of the Selma.

The Porters Creek formation crosses the county in a belt 4 or 5 miles wide, which extends from the southern projection of the county on the Hardeman-McNairy county line in a direction somewhat east of north to the extreme northern part of the county on the Madison-Henderson county line. Much of the Lafayette has been removed from the Porters Creek area, so that its leaden-gray clays are exposed in numerous places. The Lagrange sands are found in the western part of the county, covering an area 3 or 4 miles wide.

The Lafayette is 10 to 20 feet thick and overlies all the older formations. Near the eastern edge of the county it contains a considerable amount of rounded gravel. To the west the gravel becomes less abundant.

Water resources.—The streams of the county are numerous and furnish in most cases a sufficient supply of water for stock. In a few cases ponds are used. In the rough and broken country in the eastern part of the county good springs flowing from the base of the Lafayette or from the Ripley sands are numerous and much used. The surface of the county is gently rolling or almost level to the west, and the springs are less abundant and valuable, though even in the more level portions springs may be found in the depressions along the streams. The main dependence for water in this part of the county, however, is on wells. The water level in the Ripley sands is generally deep. Good, unfailing wells run from 75 to 150 feet in depth. The worst water in the county is found in the Porters Creek area. As found in some wells, certain parts of this clay are reported to be as black as tar and to emit a strong, offensive odor. Water from these clays is usually small in quantity, hard, and of a disagreeable odor, which renders it unfit for use. In the lower half of the Porters Creek occur some fine-grained, silty sandstones, and water obtained from these beds, though still hard, is in larger quantity and usually without bad odor. In the Porters Creek area wells should either be stopped in the lower part of the overlying Lafayette, if this is locally thick enough to furnish a supply, or should be carried down entirely

through the Porters Creek to the underlying Ripley sands, in which water of good quality, rising to a level somewhere near the surface, should be obtained.

At Brinley, where the Ripley sand is the surface formation, there are some wells 30 to 50 feet deep and others 90 to 130 feet deep. The deeper wells are bored, 10 to 12 inches in diameter; they furnish soft water. Some springs are in use.

At Cabo, also in the Ripley area, there are numerous springs and some weak, shallow wells. The best wells are bored, 100 to 125 feet deep; they strike good, soft water at 90 to 100 feet, usually though not always in large quantity, the variation depending on the texture of the sand.

At Deanburg, which is situated on a flat ridge between two creeks, an abundant water supply is obtained from the Lagrange sands at a depth of 50 feet. Along the creeks are numerous never-failing springs, fed from the Lafayette and Lagrange sands. All the water here is soft.

At Enville the supply is derived from wells 15 to 30 feet deep and rather weak in flow. Better and larger supplies could be obtained by drilling 200 to 300 feet through the Selma clay into the Eutaw sand.

At Henderson, elevation 421 feet, a supply of soft water is obtained from the upper part of the Ripley sand at a depth of 50 to 60 feet. Bored wells 5 to 10 inches in diameter are in common use. A "blowing well" is reported, from which air is said to escape, especially in damp weather and in winter. This is of the usual type of blowing wells, in which air is absorbed by the porous sands during high-barometer conditions, to be given out with more or less noise when the pressure is decreased, with a falling barometer.

At Jasper some springs are used. Wells are generally very shallow because the "soapstone" (Porters Creek clay) is soon struck and yields water unfit for use. A few bored wells obtain a potable but hard water from a firm sand or sandstone in the Porters Creek at 70 or 80 feet.

At Mifflin water of fair quality is obtained from the Porters Creek clay at depths ranging from 30 to 60 or 70 feet.

Montezuma lies just about at the eastern edge of the Porters Creek area, and outside of this area good water is obtained at depths of 20 to 70 feet. In the "soapstone" belt wells may go 100 to 150 feet and then be abandoned from failure to get water or from its foul odor. The water so obtained often contains iron and sulphur and is astringent and hard. There are numerous springs along the streams, and some of them contain iron or other mineral matter.

At Sweetlips, where the Ripley sand is the surface formation, good, soft water is obtained from wells 70 to 100, or, in some cases, 200 feet

deep. Along the foot of the hills good springs are found. In some cases water is raised from the deeper wells by windmills.

CROCKETT COUNTY.

Topography.—Crockett County is elongated in a northwest-southeast direction and lies between Middle Fork of Forked Deer River on the northeast and South Fork of the same river on the southwest. It has an area of 267 square miles. The surface of the county is divided along a northwest-southeast line through its center into two slopes, one draining to the northeast into Middle Fork and the other to the southwest into South Fork of Forked Deer River. The central portion is a level and gently rolling upland, with an average general elevation of about 400 to 425 feet above sea level. Near the main rivers on either side, especially in the western, northwestern, and eastern portions, the surface is hilly, being cut up by the tributary streams. The highest portion is along the central dividing ridge near the southeast end of the county, with an elevation of about 425 feet. The lowest portion is along the two forks of Forked Deer River where they leave the northwest end of the county, and has an elevation of about 300 feet.

Geology.—The Lagrange formation underlies the entire county beneath a thin blanket of Lafayette sand and gravel, which forms the surface of much of the county, but is itself covered, especially in the northwest end, by a few feet of loess and loam. The Lagrange, while predominantly of light-colored sand, contains in the southeastern part of the county beds of light-colored clays and in the northwestern part clays dark with lignitic material that is pure enough in places to burn when dried. The sands which make the bulk of the Lagrange deposits are mostly fine grained, but local beds of coarser sand occur at irregular intervals and furnish the most abundant supply of water as well as the most favorable location for setting strainers.

Water resources.—The surface is one of gentle relief, and as water sinks rapidly through the loose, porous sand of the Lagrange there is in many cases no opportunity for springs to form, so that they are not abundant and the few which occur as a rule have a weak flow. Aside from the rivers that border the county on two sides there are no streams of great importance. Pond Creek, the largest stream in the county, flows northwestward from Alamo, and Cypress Creek flows northwestward through the eastern part of the county. The other streams are very small and usually go dry during the summer, so that for watering stock the inhabitants depend largely on artificial ponds. For domestic supply wells and cisterns are in use. The wells include almost all classes. The old wells are largely dug and 20 to 30 feet deep. More recently, bored wells 6 to 12 inches in diameter and pipe wells about 2 inches in diameter have come into use. The water table

in the Lagrange sand is often at some distance below the surface, so that if water is not obtained at 20 or 30 feet in the base of the Lafayette, it is necessary to go from 100 to 200 feet to get an adequate supply in sand coarse enough to be checked by a strainer. None of the wells in the county flow and the water in some stands so low that it is raised by windmill, gasoline, or steam power. The water is generally soft. In places, that derived from the Lagrange contains iron.

Alamo is situated near the center of the county on a plain with a surface of Lafayette sand. Some cisterns are used. Shallow, open, or dug wells get water from the base of the Lafayette. Of recent years small bored wells from 80 to 200 feet deep have come into use and furnish a good and abundant supply. Windmills are used to pump some of the deeper wells.

At Bells, elevation 331 feet, a good supply of water is obtained by driven or tubular wells from the Lagrange sand at a depth of 85 to 100 feet, though some wells are 140 feet deep. The water rises within 30 or 40 feet of the surface.

At Cairo soft water is obtained from shallow wells about 30 feet deep and water which is reported as hard, but which more probably is chalybeate, from driven wells 150 feet deep. Water in the deep wells is struck at 140 feet and rises 90 feet in the pipe.

At Chestnut Bluff, on Forked Deer River, there are numerous springs at the foot of the hills. The wells, open and bored, range from 30 to 80 feet in depth. Blue clay is reached at about 30 feet, and in places, especially toward the west, it contains lignite. Wells stopped at this depth get good water from the overlying Lafayette sand, but in dry seasons they are apt to fail entirely. The deeper wells get a supply of hard water from beneath the clay. Wells for boiler supply are driven to 100 feet or more.

At Crockett Mills there is an abundance of water in quicksand at 30 to 50 feet, but this is so fine that strainers can not keep it out of the wells and they are sunk until coarser sand is reached or the depth becomes so great that the attempt is abandoned. The abrupt variation in the texture of the sand and the very small extent of any one coarse bed are shown by three driven wells here that are 132, 240, and 420 feet deep, respectively. They furnish large quantities of soft water that contains some iron. No record of the 420-foot well was obtainable, but the section is described as being alternating sand and clay, the sand being the more abundant. Water is pumped by steam or by windmill.

At Foster there are very few springs. Open, shallow wells are in general use.

At Friendship springs are but little used. Bored wells of 18-inch diameter range from 32 to 75 feet in depth, according to elevation chiefly. Driven wells 2 or 3 inches in diameter range from 85 to 100

feet in depth. The supply is abundant and is used for all purposes. Some wells contain iron.

At Maury City wells varying from 53 to 135 feet in depth furnish a good supply of water. They are pumped by hand or by gasoline engines.

DECATUR COUNTY.

Topography.—Decatur County lies just west of Tennessee River. The surface slopes eastward and the drainage is into the Tennessee. The western portion of the county has the greatest elevation. It is almost flat in places remote from the small streams that drain it, but along the streams the surface has been cut by erosion into hills. The elevation in this western part of the county ranges from 380 feet along the streams to about 550 or 600 feet on the highest ridges.

Geology.—Only the western two-fifths of the county is within the embayment, the remainder lying within the area of Paleozoic limestones. The line between these two geologic divisions runs with some sinuosities in a general north-south direction, passing through Decaturville and Parsons. It is not difficult for even the layman to recognize this line, for west of it the rocks are all soft sands and clays, while east of it they are hard limestones and cherts. The eastern part of the county, within the Paleozoic area, is not discussed in this report.

The oldest surface formation in the western part of the county is the Eutaw sand, which lies immediately on the hard Paleozoic rocks. One of the best sections, at Parsons, is described at some length on page 24. The exposure there and in railway cuts just to the west may be regarded as typical of the formation. The Eutaw sand extends westward into the adjoining county. In the extreme northwest corner of Decatur County it is overlain by the clays and marl of the Selma clay in a very small area covering not over 2 or 3 square miles.

Spread thinly over the Eutaw sand and extending eastward over the Paleozoic rocks as well is the Lafayette. In many places it has been cut through by erosion. Its proximity to Tennessee River is reflected in the large amount of rounded chert gravel it contains. This gravel is exactly similar to that now being carried down by the river. In many places the Lafayette gravel is cemented by limonite into a conglomerate, while here and there the iron is rich enough to be mined as an ore.

Water resources.—No attempts have been made within the embayment area of Decatur County to sink wells deeper than about 80 or 100 feet. The underlying formation is the Eutaw, which yields water of good quality in the sandy layers at depths varying according to the topography from 30 to 80 feet. The supply is usually abundant. There are also in this formation numerous beds of clay that contain lignitic material and decomposing iron pyrite. Water from wells or

springs supplied by these strata sometimes contains sulphur and is usually more or less astringent from the iron sulphate present. In some cases the water on standing deposits a yellowish scum of hydrated iron oxide formed by the decomposition of iron carbonate.

At Beacon the supply is derived chiefly from wells of ordinary depth, those stopping in sand giving water free from mineral matter, while those in clay contain iron salts.

Parsons, elevation 488 feet, is situated on the eastern edge of the embayment deposits. Springs from the base of the Eutaw formation often contain iron and sulphur. Wells are generally used, and average 25 to 35 feet deep. Those dug to the sand and gravel at the base of the Eutaw obtain a good supply of pure, soft water; those stopping in an overlying clayey stratum obtain a less abundant supply of hard water, which may fail entirely in a dry season. Wells are either open, bored, or driven. There is no waterworks system in the town.

At Point Pleasant a supply is obtained from ordinary open or driven wells and from numerous springs along the bottom or lower slopes of the hills.

At Sugar Tree there are only shallow wells; the water in some of them is said to contain alum, while in others it is free from mineral ingredients. There are a few springs.

At Thurman the chief supply is from open wells that range from 30 to 80 feet in depth. Some springs are used.

DYER COUNTY.

Topography.—Dyer County is in the northwestern part of the embayment area of western Tennessee. It is bounded on the west by Mississippi River and on the south by Forked Deer River and its South Fork. The area is 500 square miles. The drainage is to the Mississippi directly or through Ohio River, Forked Deer River, or Reelfoot Lake.

The county may be divided into two parts that are topographically quite distinct. One is the rolling or hilly upland region, lying chiefly in the eastern half of the county. The other is the flat, alluvial bottom land of the Mississippi, the Obion, and other main streams. The upland is gently rolling except along the streams, where it becomes hilly, and along the line of bluffs separating it from the Mississippi bottom, where erosion has cut it into bold, steep hills that form the bluffs and overlook the broad expanse of bottom lands. The average elevation of the upland surface is about 375 feet, while that of the bottoms is from 100 to 150 feet less.

Geology.—The formations of importance for water-supply purposes in Dyer County are the Lagrange, the Lafayette, the loess, and the alluvium.

The Lagrange underlies the entire county. Although it is occasionally laid bare in ravines by the erosion of the overlying formations, it is generally concealed by one or more of these formations and is reached in wells at depths of 50 to 100 feet. It is the important water bearer of the area.

The Lafayette underlies the upland area of the county, resting on the Lagrange. It averages not over a score of feet in thickness. The Lafayette is not found beneath the bottom areas, because since its deposition it has been removed by the erosion which formed the stream valleys. It does not appear as a surface formation, except where the loess has been removed by erosion. It lies just beneath the loess and is reached in many wells.

The loess, like the Lafayette, occurs only in the upland part of the county and the second bottoms, and for the same reason it has elsewhere been removed by subsequent erosion. It rests on the Lafayette and often contains a stratum of gravel and sand at its base. It has a maximum thickness of 40 to 80 feet along the bluffs of the Mississippi, but thins out and gradually disappears to the east, so that a definite eastern limit for it can not be fixed. However the eastern edge of the county may be roughly taken as that limit.

The alluvium is found in the bottoms of the Mississippi and other streams. It rests directly on the Lagrange and varies in thickness up to 100 feet or more along the Mississippi. Along Obion and Forked Deer rivers the valley is divided topographically into a first and a second bottom. The first bottom is low and usually swampy and composed of alluvium. The second bottom is 10 to 20 feet higher as a rule and covered with loess.

Water resources.—In the more broken parts of the county, near the streams, springs issue from the Lafayette along the lower slopes of the hills. In the more level parts the open shallow wells in the loess usually yield hard water and early led to the use of cisterns. These are very easily and cheaply constructed in the loess and are extensively used. Of recent years driven wells 2 or 3 inches in diameter have come into use. These obtain a supply of fair to good water in the Lagrange at a depth of 150 to 250 feet, as a rule. The water is usually soft enough to use in washing, but may leave a soft or gummy scale in boilers. Water may be obtained from the Lagrange in all parts of the county, at reasonable depths, and should generally be of acceptable quality. The Lagrange here contains beds of clay, and much of the sand is fine, so that careful watch should be kept for any pocket of sand coarse enough to permit the use of a strainer. In the alluvial region the water obtained in shallow open or driven wells is generally unsatisfactory. Since the surface is everywhere either below or only slightly above high-water level in the rivers, wells in this region are shallow and draw their supplies

of water practically from the surface. The water in the wells on the elevated strip of flood plain near the banks of the Mississippi rises and falls in harmony with the varying stages of the river surface. The water from the alluvium is usually hard and flat or "sweet" in taste and must contain considerable organic matter, resulting from the decomposition of the abundant plant remains that are embedded everywhere in the flood-plain deposits. Better water may be obtained on any of the flood plains by sinking deep wells into the underlying Lagrange formation.

At Bandmill, in the Mississippi bottom, poor water is obtained from the alluvium by shallow driven wells.

At Bogota, on a tributary of the Obion, there are no springs or open wells, but water is obtained from driven wells 18 to 20 feet deep. The quality is said to be good.

At Dyersburg, elevation 295 feet, on Forked Deer River, shallow open and driven wells and cisterns are used. The shallow wells run from 30 to 60 feet in depth. The 30-foot wells in the loess get poor surface water. The 60-foot wells go through the loess and get a better water from the Lafayette sand or the top of the Lagrange. The supply from this sand is large. Five wells in it yield about 250,000 gallons a day, but the water is hard and that from some of them scales badly in boilers. The old water company had an artesian well 6 inches in diameter and 650 feet deep, with a natural flow of about 150,000 gallons a day rising about 10 feet above the well mouth. When pumped the well was capable of yielding 1,000,000 gallons a day with proper air lift. The log, given from memory, is as follows:

Log of well at Dyersburg, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Red clay	10	10
Blue clay	40	50
Sand, very fine on top, grading into a layer of pebbles 1 inch in diameter at bottom	40	90
Soft light-colored clay	25	115
Quicksand	30	145
Thin layers of fine sand and dark tough clay with lignite	275(?)	420 (?)
Sand, fine and coarse to bottom	230(?)	650

The water has not been analyzed, but it is not good for boiler or general industrial use, so that the municipal corporation which has bought out the old private water company now takes the town supply from Forked Deer River and forces it by two 1,000,000-gallon Worthington pumps into a standpipe 27 by 50 feet in size and 125 feet above the pumps. The supply is filtered by Jackson mechanical filters.

The Phœnix Cotton Oil Company has a well, drilled in 1899, at

about the same elevation as the town well, and 591 feet deep. For the upper 200 feet the diameter is 8 inches; below that, 6 inches, with a 30-foot strainer. The log, given from memory by one of the proprietors of the mill, is as follows:

Log of well of Phœnix Cotton Oil Company, Dyersburg, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and sand	200	200
"Soapstone" or hard pipe clay	+350	+550
White sand, mostly coarse	41	591

At 200 feet a weak flow of water containing considerable mineral matter was encountered. The natural flow is at first 100 gallons a minute under a head of 11 feet. This flow decreases slowly until the strainer is washed out by back pressure and then resumes its original volume. The water contains 138 parts per million of mineral matter, 114 parts of which are iron salts. The water flows naturally into a pool, which was at first shallow and aerated it sufficiently to cause most of the iron to be precipitated. The pool has lately been deepened and now aeration and precipitation are imperfect and a yellowish rust-colored soft scale is deposited in the boilers.

Another log of these two wells was given—also from memory—by Johnson and Fleming, of Memphis, who drilled both wells. It is as follows:

Log of well of Phœnix Cotton Oil Company, Dyersburg, Tenn.

	Feet.
Loess	5
Fine sand and gravel; gray-black in color	40 or 50
Silt, gray to black, full of leaves and lignite to 220 feet from surface	165 or 175
Blue clay, with leaves and logs	360
White pipeclay	20
White sand with fine particles of lignite and iron pyrite	28

They report the town well as 584 feet deep and the oil company's as 628. The oil company's purchase of pipe and strainer shows only 591 feet.

West of Dyersburg in the bottoms driven wells 2 inches in diameter and 10 to 40 feet deep are used. The water is poor and flat or "sweet." East of town, on the upland, wells average about 40 feet deep.

At Finley cisterns are used very largely.

At Lane there are a few springs, several open wells, some cisterns, and a number of driven wells 75 to 125 feet in depth. An approximate log of one of these is as follows:

Log of well at Lane, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Red clay, becoming lighter downward	35	35
Blue clay	25	60
Sand, fine-grained, water-bearing	5	65
Blue clay	15	80
Sand, coarser, water-bearing	10	90
Blue clay, somewhat chalky	25	115
Sand, course, with gravel, water-bearing	5	120

The supply is abundant but the water is hard.

At Laplata water is obtained from shallow wells that average 30 feet in depth.

At Newbern, elevation 380 feet, cisterns were formerly much used. There is a town system of waterworks deriving an abundant supply from two wells, each 165 feet deep; one of 5-inch diameter, put down in 1892, the other of 8-inch diameter, put down in 1897. The water rises within about 70 feet of the surface. The supply is ample for the two pumps, which have a combined capacity of 8,000 gallons per hour. The water is soft and very good for washing. It forms a little soft scale in boilers which is easily removed by a boiler compound. It does not injure the iron, but corrodes brass connections rapidly. The health of the town is said to have been materially improved by the use of this water. Typhoid and malarial fevers especially have decreased in frequency. There are other wells of about the same depth at the Illinois Central Railroad water tank, the ice plant, a planing mill, and a flouring mill.

A generalized section given by Mr. J. L. Holt, a Newbern well driller, is as follows:

Generalized section at Newbern, Tenn.

	Feet.
Yellow clay (loess)	30±
Sand, fine, only a little water in it (Lafayette)	4±
Joint clay, or soapstone, bluish gray	30–60
Quicksand, fine, silty, down to a total depth of 130–150 feet	35–85
Coarse yellow sand, penetrated	10–15

At the planing mill, on about the same level as the town well, no joint clay was encountered. Thirty feet of loess were followed by a quicksand that became coarser downward until the strainer was set at 110 feet depth.

Two miles west of Newbern the following record was obtained in a well made for Mr. Kit Haskins:

Log of Haskins well near Newbern, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellowish on top	50	50
Clay, reddish	50	100
Clay, blue	50	150
Clay, white	45	195
Sandstones	2	197
Sand, coarse, yellow, penetrated	13	210

Eight miles west of Newbern water was obtained on the upland for Mr. Guy Fairbanks at a depth of 156 feet. The section was as follows:

Log of Fairbanks well near Newbern, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow (loess)	50	50
Clay, blue (loess ?)	40	90
Sand and gravel with 2-foot indurated layer at base (Lafayette ?)	12	112
Quicksand with some gravel, penetrated (Lagrange)	54	166

Five miles south of Newbern, on the uplands north of Forked Deer River, a hard water not fit for boiler use is obtained at a depth of about 325 feet. The water rises to within 75 feet of the surface. The strata passed through were as follows:

Log of well on Forked Deer River near Newbern, Tenn. [a]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, yellow (loess)	40	40
Sand, very fine, doughy	100	140
Clay, blue, tough	85	225
Sand, fine, blue, penetrated	100	325

[a] Figures are approximate.

Along Obion River wells on the first bottom average 50 feet in depth. They usually pass through blue mud from 20 to 50 feet thick and enter a bluish muddy sand, in which the well is made. Occasionally a pocket of gravel is encountered beneath the blue mud. On the second bottoms, which rise 15 to 25 feet above the first bottoms, and are from 4 to 12 miles wide, the average depth of wells is about 110 feet, and the average record is, from the top down, yellow to gray clay (loess), 20 to 40 feet thick; blue mud, often very soft, 20 to 30 feet thick; muddy quicksand as in first bottoms. There is no Lafayette gravel between the yellow clay, or loess, and the underlying blue mud of the Lagrange. In the cutting of the broad valley represented by the second bottom the Lafayette was removed; the loess was then laid down alike over upland and valley floor; then uplift came and the loess was removed from the area now occupied by the streams and the first or present bottom.

On the uplands east of Newbern, toward Trenton, water is usually soft and is reached at about 50 to 55 feet. In some spots, which are not necessarily high places, one must go 90 or 100 feet to obtain an unfailing supply. In this region the loess soon thins out and disappears, and hence the water is apt to be soft.

At Templeton driven wells range in depth from 30 to 150 feet. The deeper ones yield an unfailing supply of water that is usually soft, but in some cases contains iron and other minerals. The water

here, as elsewhere in the county at any notable depth, is obtained from sands of the Lagrange formation.

At Tennemo, on the Mississippi, poor water is obtained from shallow driven wells; river water is also used.

At Tigertail small driven wells average about 30 feet in depth.

At Trimble there are a few cisterns, but water is obtained mainly from driven wells that range from 40 to 110 feet in depth and furnish a good supply. The water in the shallow wells is hard; in the deeper ones it is somewhat soft and is used for boilers without much difficulty. The loess is about 30 or 40 feet thick and is underlain by a blue clay, often so soft as to run, 4 to 10 feet thick, followed by a fine quicksand, which usually becomes coarse enough at a depth of 80 to 110 feet to make the well there.

FAYETTE COUNTY.

Fayette County is in the southwestern part of the area discussed, and is bordered on the south by the State of Mississippi. Its area is 618 square miles. The entire county drains into Wolf, Loosahatchie, and Hatchee rivers, which are all tributary to the Mississippi. The larger part of the area is elevated and rolling. In the southeasten part of the county there are hills adjacent to the Wolf River valley. In the northwestern part the county on either side of the Loosahatchie is broken and hilly. The southeastern part of the county is the highest. Lagrange has an elevation of 531 feet, and elsewhere in the vicinity elevations of 550 to 575 feet are found. The general slope is westward, and the lowest elevation, about 260 feet, is on the western edge of the county, where Loosahatchie River leaves it.

Geology.—The underlying formation is everywhere the Lagrange. It is exposed in many places in the ravines and deep gullies, and contains clay beds that are mined in a number of places. The section at Lagrange, from which place the formation takes its name, is given on page 36. It is overlain by 10 to 20 feet of orange-colored sand belonging to the Lafayette, and this in turn by a few feet of Columbia sand or loam, or, in the northwestern part of the county, by the thin eastern edge of the loess.

Water resources.—As a rule, springs are not numerous in this county. The Lagrange consists here very largely of sands which absorb water freely, and contains comparatively few beds of clay extensive enough to intercept the water in its downward passage and guide it to the surface along their outcrops to form springs. The water table or ground-water level lies here farther from the surface than is the case either to the east or the west of this outcrop belt of the Lagrange. Springs are generally freestone. The depth to water, which is in many places 75 to 150 feet, makes open wells

expensive and inconvenient, and so cisterns are largely used. Driven wells 2 or 3 inches in diameter have in recent years come into use in many sections. The deeper ones are usually pumped by windmills or by gasoline or steam engines. The quality of the water from the Lagrange sand is generally good. Occasionally a well strikes a bed of lignitic material and the water then contains iron and sulphur. In places weak flows may be obtained at the base of the Lafayette. As a rule, such water can not be depended on during dry seasons. It seems to gather in little local depressions on the upper surface of the Lagrange, being held up by an impervious crust of ironstone, which in places is found at the contact between these two formations, but which may be wanting within a hundred yards. If this impervious layer is penetrated, the Lagrange sand beneath is generally found dry, and one may dig 50 or 100 feet deeper, or more, before getting water in this formation. Water should be obtainable anywhere in the Lagrange at depths of not more than 200 or 250 feet, and in many places it is found at a depth considerably less. The streams of the county are numerous and except in dry seasons have an abundant flow. Some of them have considerable fall and furnish sites for small mills.

At Canadaville there are no springs, but most of the inhabitants use cisterns. Some small bored wells, ranging from 90 to 140 feet in depth, yield an abundant supply of good soft water, but in the deeper wells it rises only within 125 feet of the surface.

At Claxton only ordinary and driven wells are used. The latter may go 75 to 100 feet deep, and the water rises within about 40 feet of the surface. The water is soft and the quantity ample.

At Elba there are a few springs. The main water supply comes from bored wells of shallow depth.

At Gallaway, elevation 277 feet, a few cisterns are in use, but most of the people have shallow wells that derive their supply from the Lafayette sand beneath a loess covering. The water is consequently hard.

Ina is on an elevated plateau 500 feet above sea level. There are a few springs, but they are usually weak. The principal water supply is from ordinary pipe wells of small diameter that average 75 to 125 feet deep and furnish good soft water.

Lagrange is on an elevated ridge 532 feet above the sea. A detailed discussion of the geology is given on page 36. Wells are the main dependence for water. They vary greatly in depth. Some find water at 18 to 20 feet depth at the base of the Lafayette; others a few hundred yards away go 175 to 213 feet before getting a supply in the Lagrange sand. The water is soft and pure, but does not rise in the wells. Windmills are used for pumping.

At Lambert there are some springs along the streams; on the upland surface water is obtained from ordinary open wells.

At Macon most of the water is obtained from bored wells at depths of from 35 to 100 feet. There are a few springs, but they are along the streams and not convenient for use.

At Moorman small driven wells are largely used. One 103 feet deep struck water of good quality at 53 feet. It is pumped by a windmill. Others go as deep as 200 feet.

At Moscow, elevation 354 feet, the wells average 30 to 40 feet in depth. At that depth the flow is weak, but below the blue mud struck there water is found in abundance at depths of 60 to 80 feet. In the hills east of town water is reached at 90 to 100 feet.

At New Kent there are some wet-weather springs, but water is generally obtained from bored and dug wells. The supply from these is not always satisfactory, and many are reported to have gone dry after a few years.

At Oakland, elevation 388 feet, the wells are from 60 to 125 feet in depth. They are pumped by hand, or by steam where used for industrial purposes.

At Rossville, elevation 311 feet, water is obtained from white sand beneath a layer of pipe clay at 28 to 35 feet. It is soft, but contains some iron.

At Somerville, elevation 356 feet, the supply is furnished by open wells and driven wells from 100 to 150 feet deep. The water rises in some of these within 50 feet of the surface. It is in several cases reported hard. The supply is abundant.

At Taylors Chapel water is obtained from some good strong springs and wells that range from 25 to 125 feet in depth. In many places at depths of 30 to 40 feet a stratum of black mud is struck, averaging about 40 feet thick and furnishing foul-smelling water. It is underlain by a thin ironstone layer and when this is pierced good water, that rises 30 or 40 feet, is found in abundance. It is usually pure, but occasionally contains some iron or sulphur.

Yumyum has very few springs. Bored wells ranging from 30 to 40 feet in depth furnish a scant supply, but an abundance is reached by driven wells at depths of 125 to 200 feet.

GIBSON COUNTY.

Topography.—Gibson County is situated almost in the center of the embayment area of western Tennessee. Its shape is roughly a rectangle from which the northeast and southwest corners have been removed. It is bounded on the northeast by South Fork of Obion River and on the southwest chiefly by Middle Fork of Forked Deer River. The area is 625 square miles.

The entire county is in the Mississippi drainage area. The surface

slopes gently to the northwest, and is mostly level or slightly rolling, for, as a rule, the streams have not cut deeply below the general level; only in the southern and eastern parts of the county is the surface broken or hilly. The stream valleys or flood plains are usually wide and the valley sides have moderate slopes. The streams do not have much fall, but flow gently, and are rather building up their flood plains than cutting them out. The greatest elevation is in the southeast corner, where it reaches slightly above 500 feet. The least elevation is about 280 feet, at the point where Forked Deer River leaves the western edge of the county. The average elevation of the upland is about 400 to 425 feet.

Geology.—The rocks that outcrop in Gibson County are the Lagrange, the Lafayette, and the Columbia loam and loess.

The Lagrange underlies the entire county and is the source of all deep waters. Because of the gentle character of the stream cutting it is not usually exposed. It consists here as elsewhere of sands and clays, the sands predominating.

The Lafayette rests upon the Lagrange on the uplands and the upper part of the valley slopes. It is here chiefly a red loamy or case-hardened sand and contains very little gravel. It averages perhaps 20 or 30 feet in thickness.

A few feet of light-colored Columbia loam usually overlie the Lafayette, and it is often hard to distinguish one formation from the other. In the northwestern part of the county this loam apparently passes into the loess.

Water resources.—The various tributaries of Obion and Forked Deer rivers provide most of the county with water for stock. Some portions of the county, however, are remote from streams and there ponds are dug in low places to catch water. For domestic use wells are the most common source of supply. To a limited extent cisterns are used, especially in the middle and western parts of the county, on the more elevated uplands, where wells would be in some places inconveniently deep. Along the sides of the valleys springs occur, but most of them come from the base of the Lafayette and have a weak flow. The wells range in depth from 25 to 35 feet in the low grounds near the streams and from 100 to 125 feet on the uplands. Exceptionally they may reach 200 feet, as in some places in the elevated southeastern part of the county. The water is generally soft where it does not come from the loess, which occurs in the northwestern part of the county. It is generally free from mineral matter, though in places where lignitic beds are present in the Lagrange it may contain iron and sulphur. Water in the deeper wells may rise on the uplands a good part of the way to the surface, while on the second bottoms and along the streams it rises just to or slightly above the surface. Many wells in low places that flow gently when first

drilled stop flowing after a time, because of the partial choking up of the pores in the sand around the strainer by fine particles carried there by the flow of water to the well. In such cases back pressure by a pump washes the sand clean and restores the original flow for a time.

At Bradford, elevation 366 feet, water is obtained from dug and bored wells that vary in depth from 10 feet in low places to 160 feet on high ground. Usually an abundance of water may be had at 40 feet or less. Springs are few, small, and weak.

At Cades, elevation 374 feet, a black lignitic clay 90 feet thick is struck at a depth of about 30 feet. Beneath this is a water-bearing sand. In a well 140 feet deep the water stands 30 feet below the surface.

About 2 miles north of Cades the lignitic clay is absent. A well on the Fletcher Neal farm went 175 feet through sand only and obtained good water at 160 feet, but the water did not rise above that level.

At Clareville water is obtained chiefly from open and bored wells of 50 feet depth or less. There is a sulphur spring of local note only.

At Dyer, elevation 358 feet, both wells and cisterns are used. The wells average from 20 to 60 feet in depth. Some of the water is hard and the supply is usually not large. One well is reported 200 feet deep, but no further data concerning it could be had. A mile west of town there is a strong spring of pure soft water that has determined the location near it of a Methodist camp-meeting ground.

At Eaton there are few springs except along the edge of the Forked Deer bottom. Wells range from 20 to 40 feet in depth.

At Edmonds a plentiful supply of good water is obtained, mostly from small bored wells. There are a few open or dug wells. The depths of all are moderate.

At Gibson, elevation 389 feet, the bored wells range from 20 to 100 feet in depth, though the average is about 60 feet. In the deeper wells water rises 20 or 30 feet.

At Hooten there are a few springs. Most people have bored or dug wells that reach an abundant supply of water at from 20 to 40 feet.

At Laneview open and small bored wells range in depth from 50 to 130 feet. In a 128-foot well, the water stands 110 feet from the surface.

At Lonoke ordinary wells range from 15 to 100 feet in depth, according to location, and small pipe wells from 100 to 300 feet. The water is soft, but in some of the deeper wells contains iron or sulphur.

At Medina, elevation 502 feet, it is necessary to go to a depth of from 100 to 200 feet for water, and sometimes even at the latter depth

the Lagrange sands fail to furnish a supply. The water is soft and pure where obtained.

Milan, elevation 421 feet, is underlain by about 20 or 22 feet of red Lafayette sand, below which in a part of the town is found a pipe clay 43 feet thick, while elsewhere, especially in the eastern part of town, instead of pipe clay a very dark or black lignitic clay is struck. This black clay occurs 3 or 4 miles north of town and for the same distance south. It reaches a thickness in places of 70 to 90 feet. Under it are 2 to 7 feet of yellow clay, then a 3 or 4 inch ironstone crust, easily broken by an iron bar. Below either the pipe clay or the ironstone is found a soft sand which varies in texture but often contains in its upper part some fine gravel. This sand is water-bearing and has been explored to a depth of 200 feet from the surface. The town corporation has two 6-inch wells, each 113 feet deep, with 20-foot No. 6 Cook strainers. The water rises within 20 feet of the surface. It is pumped into a large cistern or reservoir and is forced thence into the mains under a service pressure of 40 to 45 pounds and a fire pressure of 100 to 125 pounds. The water is very clear and is said to be good for all purposes. It forms in boilers a very small amount of soft scale. The pumps have a capacity of 500,000 gallons per day. The actual daily consumption averages 60,000 gallons. Open wells get surface water at the base of the Lafayette at depths of 20 to 25 feet. This water is usually unsatisfactory and the best open or pipe wells are from 65 to 90 feet deep. They tend to fill up, however, with the fine soft sand in which they stop. On the higher hills in the vicinity the wells go 100 or 125 feet deep, and in such localities an occasional cistern is found. Elsewhere in this vicinity cisterns are not used.

At Neboville there are along the water courses some small springs that are used for stock. Wells average from 40 to 80 feet in depth. The water is generally soft.

At Rutherford water is obtained from dug wells 50 to 70 feet deep; it is reported hard in some cases. Driven or pipe wells averaging about 160 feet in depth are also used.

At Skullbone there are no springs; water is obtained from open or bored wells, some of which are 90 feet deep, with the water standing 70 feet from the surface.

At Trenton, elevation 315 feet, a town supply is obtained from four 4-inch wells 119, 147, 152, and 165 feet deep, and two 6-inch wells 130 and 165 feet deep. In the 130-foot well the strainer is 24 feet long; in the others 16 feet. Five are in a row only 22 feet apart; the sixth is 40 feet distant from this row. As a consequence they interfere with each other. They have a combined natural flow under a head of about 2 feet of 90 gallons per minute. Except in case of fire and during July, August, and September, when daily consump-

tion is at a maximum, the natural flow is adequate for all purposes. The two pumps have each a capacity of 250,000 gallons per day and force the water into the mains under a service pressure of 45 pounds per square inch. The water is very clear and pure and since 1897, when the system was installed, the health of the town has notably improved, fevers especially showing a marked decrease. In sinking the wells 15 feet of a second-bottom deposit of sandy clay was first passed through and then a water-filled sand which extends down 155 feet and is followed by 1 foot of sand ironstone and that by a light-colored pipe clay which was not explored further. The sand in which the strainers were set is very fine and some gets through even a No. 6 Cook strainer, so that as little pumping as possible is done. Common open wells in town run from 20 to 40 feet deep, and some cisterns are still in use. These are now generally filled from the city mains and during the hot months keep the water cooler than it is in the mains. A stave mill, a fourth of a mile north of the town wells has a 4-inch well 147 feet deep, with a record similar to the town wells. In the surrounding country the open wells vary from 20 or 25 feet in depth in the stream valleys to 100 feet on the uplands. Some cisterns are in use.

At Yorkville there is a mineral spring of some local repute.

HARDEMAN COUNTY.

Topography.—Hardeman County adjoins the State line on the south and is almost halfway between Tennessee and Mississippi rivers. It is quadrangular in shape, with a small irregularity in the northeast corner. Its area is 655 square miles. The central and western parts of the county are gently rolling and the northern, eastern, and southern parts are broken and hilly. The county is drained almost entirely by Hatchee River and its tributaries. The course of the Hatchee is from southeast to northwest through the center of the county, and its tributaries on either side have their general courses almost at right angles to the main stream. The most elevated part of the county is the southwestern, where the higher ridges or remnants of the former plateau surface reach altitudes of slightly over 600 feet, and the general elevation is between 500 and 600 feet. The rest of the county averages between 400 and 500 feet. The lowest point is about 300 feet, where the Hatchee leaves the county. The general surface slope is northward or northwestward.

Geology.—The geologic formations of Hardeman County are the Ripley, Porters Creek, Lagrange, Lafayette, and Columbia.

The Ripley is found only in a narrow belt along the extreme eastern edge of the county, east of Muddy Creek near Middleton and east of Crainesville. It has its usual character, consisting of soft light-colored or variegated sands with occasional thin clay lenses.

The Porters Creek overlies the Ripley and succeeds it to the west as a surface formation. It runs through the eastern part of the county in a direction slightly east of north in a belt that averages from 6 to 9 miles wide. Its eastern edge along the Southern Railway is just east of Muddy Creek near Middleton and passes through Crainesville. Its western edge may be seen on the road from Bolivar to Crainesville just east of the bridge over the Hatchie. Much of it is a fine clay, ashen gray when dry but darker when wet, and is popularly known as soapstone. A more sandy phase is sometimes known as alum earth.

The Lagrange lies west of the Porters Creek belt and underlies all of the central and western parts of the county. While predominantly of sand, it contains lenses of plastic clay and occasional beds of lignitic material.

The Lafayette has its usual character, being a surface veneer of orange-red sand found on the higher levels, 10 to perhaps 40 feet thick. Over it in places may be discriminated 5 to 10 feet of lighter-colored, softer sand representing the Columbia.

Water resources.—The county is naturally well watered. Streams are found everywhere within short distances and furnish ample supplies for stock. Their flow is fairly constant, since most of the water comes from sandy formations that furnish an almost unfailing supply. Many bold springs of good freestone water flow from the sands of the Lafayette, the Lagrange, or the Ripley. The springs from the Porters Creek "soapstone" clay are weak and the water is usually astringent from alum and iron. Wells in the sands obtain good water. Where the Lafayette is locally thick wells often reach water in its lower part above an iron crust or hardpan separating it from the underlying formation. The quantity of this Lafayette water is limited and during dry seasons it may fail altogether. Furthermore, it is surface water and so is liable to contamination. The Lagrange furnishes good pure water except where lignitic beds locally occur. There it contains iron, sulphur, or alum to some extent. The depth at which water may be obtained in it varies largely with the topography. On the uplands it is generally necessary to go from 75 to 150 feet. In a belt of very porous dry sands in this formation that extends 2 or 3 miles on either side of Grand Junction and runs northeastward to Hickory Valley and beyond it is often necessary to go 200 feet or more. In such places and also in the area underlain by the Porters Creek clay cisterns are often used. The Porters Creek furnishes unsatisfactory water. It is hard and contains iron and alum. The odor in some cases is so disagreeable that even stock will not touch it, and the supply, even where the water is of tolerable quality, is usually small. In many cases open wells, which are usually dug less than 100 feet, fail to obtain water.

Open wells should be stopped in the base of the Lafayette just above the clay if that formation will yield any water. If not, the small tubular or driven well should be used and should be put down through the Porters Creek clay to the upper layers of the Ripley sand, where a supply of good water should be struck that will rise a considerable distance toward the surface. Difficulty should not be experienced in sinking through the Porters Creek clay if struck anywhere near the surface, as it is nowhere known to be as much as 200 feet thick and is probably not greatly over 100 to 125 feet in this county.

At Bolivar, elevation 449 feet, water is obtained from wells that average 70 to 80 feet in depth. The upper 20 to 30 feet are in Lafayette sand and the rest of the section is in Lagrange sand. An unsuccessful attempt to sink a deep well was made some years ago, but the cause of the failure could not be learned. There should be no difficulty in obtaining water from the lower layers of the Lagrange, which is probably 200 feet or less in thickness here. After this is passed no water could be hoped for until the Porters Creek clay—perhaps 150 or 175 feet thick—had been gone through; then water should be struck in the upper part of the Ripley under sufficient pressure to rise within about 100 feet of the surface.

Crainesville is situated on the eastern edge of the Porters Creek clay. Wells average 40 to 50 feet in depth. Those in the clay furnish poor water, while those in the Ripley sand furnish good water. If the clay is struck, digging should be continued until it is passed through, for it can nowhere in the village be over a few score feet thick. Wells in the Ripley sand to the east are from 30 to 50 feet deep and furnish good water. Those in the alluvium of the Wade Creek bottom west of town furnish poor water at depths of 14 to 25 feet. Farther west in the "soapstone" belt good water is sometimes obtained in the basal part of the Lafayette sand just above the leaden-colored clay. If the latter is entered the water is generally poor.

At Essary Springs Hatchie River is used for stock, and springs and wells furnish the domestic supply. The wells vary from 20 to 60 feet in depth. The water in some is free from all mineral matter; in others it contains iron. The spring water commonly contains iron and is largely used.

At Grand Junction, elevation 573 feet, shallow wells in the basal part of the Lafayette at depths of 15 to 25 feet furnish a scant supply of surface water and go dry during late summer and autumn. Cisterns are largely used for domestic supply. Two driven wells of 2-inch diameter, one 145 and the other 195 feet deep, find water in the Lagrange sand. The deeper one passes through the following strata:

Log of well at Grand Junction, Tenn.

	Feet.
Clay, sandy, red (Lafayette)	12
Clay, fine, white, plastic	22
Sand, white, clean, sharp	20
Clay, white, as above	2
Sand, light red, coarse at top and bottom (penetrated)	139

Water was struck at 152 feet, but did not rise. At 195 feet the sand was coarse enough to set the strainer. This well is pumped by steam. The 145-foot well belonging to the town is pumped with difficulty by hand and is not much used.

At Hickory Valley, elevation 566 feet, shallow wells have an average depth of about 60 feet. They are not always reliable and may go dry; many of them have been abandoned for cisterns or for deep tubular wells that range from 150 to 210 feet in depth according to the topography. In some the water is very good and pure; in others it contains some iron. Similar conditions as to depth and quality prevail for 3 miles east and 3 miles west of town. Five miles to the east springs are numerous and wells average only 30 or 35 feet deep.

At Middleburg, elevation 537 feet, wells range in depth from 25 feet in the base of the Lafayette to 180 feet in the underlying Lagrange. Water is abundant and soft.

At Middleton, elevation 407 feet, water is rarely found above the dark Porters Creek clay, which is reached at a depth of 15 or 20 feet. Wells average 20 or 25 feet in depth and furnish poor to fair water. One well 102 feet deep was abandoned in the Porters Creek clay without finding water, when perhaps 50 feet more would have carried it into the underlying Ripley sand, where a good supply of soft water that would rise much of the way to the surface could have been expected. Cisterns are used to some extent, though in the main the people endure the poor water from the Porters Creek clay. It is surprising that no one has drilled through this into the Ripley, which at the farthest should be found at less than 200 feet from the surface.

At Newcastle the wells average 100 feet in depth.

At Pocahontas, elevation 394 feet, a water supply is obtained from wells that average 25 or 30 feet in depth. In the hills near by wells reach 100 feet or more in depth. The water is soft and comes from the Ripley sand.

At Rogers Springs the "soapstone" occurs near the surface. A little water of poor quality is obtained in its upper part about 35 to 40 feet from the surface. An exploratory hole 80 feet deep failed to find other water.

Saulsbury, elevation 534 feet, is situated on the thin eastern part of the Lagrange, which is capped on the higher levels by about 20

feet of Lafayette sand. Water is usually obtained in Lagrange sand at depths of 85 to 90 feet. Two miles south of town the Porters Creek clay is struck at 110 feet, and a mile west of town at 130 feet. Water was obtained in moderate quantities just above the clay.

At Toone, elevation 392 feet, water is obtained from wells and springs. Wells range from 20 to 100 feet in depth.

At Whiteville, elevation 500 feet, bored wells range in depth from 50 to 140 feet, most of them from 100 to 125 feet. The quality and quantity of the water are both good.

HARDIN COUNTY.

Topography.—Hardin County lies at the southeast corner of the area discussed in this paper, and is bounded on the south by Mississippi and Alabama. Its area is 587 square miles. Only a part of the county is within the embayment area, about two-thirds being east of Tennessee River. West of the Tennessee there are small areas of Paleozoic rocks where the river enters and leaves the county. The western part of the county slopes eastward and is drained by numerous small streams into the Tennessee. Along these streams the surface has been cut by erosion into hills. Away from the streams much of the surface is gently rolling. The highest portions are along the western boundary and average about 500 or 525 feet in elevation. The lowest point, about 350 feet, is at low water on the Tennessee where it leaves the county.

Geology.—The formations outcropping in this county are the Eutaw sand, Selma clay, and Lafayette.

The Eutaw sand lies immediately west of Tennessee River in the middle part of its course across the county and is well exposed at Coffee, Crump, and Pittsburg Landing. A section at Coffee Bluff is given on page 24. The Eutaw is found just beneath the Lafayette over all of the area except a narrow strip in the western and northwestern parts, which is underlain by the leaden-colored clays and shell marl of the Selma. Over both of these formations is spread a thin veneer of Lafayette, which is still intact on much of the upland surface, but has been removed on the stream slopes. It contains much chert gravel and is usually highly ferruginous.

Water resources.—Springs are numerous along the lower slopes of the hills. Those from the Selma clay are more or less impregnated with lime, while those from the Eutaw sand may be free from mineral matter or may contain iron and sulphur. Springs in the slight depressions occurring in the more elevated rolling portions of the county are from the base of the Lafayette and are apt to be weak. Streams are numerous but as a rule small. In the Eutaw area wells are usually open or bored, and vary from 30 to 70 feet in depth, the deeper ones being on the bluffs near the river. In the Selma area it

is necessary either to bore through the clay 200 feet or more in order to reach good water in the underlying Eutaw sand or to stop in the Lafayette before the Selma is reached, provided the Lafayette is thick enough to reach below permanent ground-water level and furnish a supply. Cisterns are but little used.

At Crump water is obtained from some good strong springs and from numerous wells, averaging 50 to 70 feet in depth. The water at this depth comes from the upper part of the Eutaw formation and is abundant and good.

At Hamburg, in the Tennessee River Valley, water is obtained from shallow wells sunk in the alluvial deposits. The quality is fair to good.

At Hurley there are several springs that furnish chalybeate water and open wells 60 to 70 feet deep that furnish good water from the Eutaw sand.

At Morris Chapel soft water is obtained from the Eutaw formation by wells from 15 to 50 feet deep. The average depth is 40 to 45 feet.

At Pittsburg Landing, in the Shiloh National Park, wells pass through 10 feet of Lafayette surface clay, 15 to 20 feet of Lafayette gravel, partly cemented by iron, and into the Eutaw sand to a total depth of from 40 to 70 feet, where good pure water is obtained. From Pittsburg Landing westward for some miles open wells averaging 40 to 50 feet in depth and drawing from the Eutaw sand are the chief water supply.

HAYWOOD COUNTY.

Topography.—Haywood County is situated somewhat southwest of the center of the embayment area of western Tennessee. It is roughly quadrangular in shape, its northern boundary, however, being quite sinuous, partly because a portion of it is formed by South Fork of Forked Deer River. Its area is 520 square miles. The surface is a gently undulating plain with an average elevation of about 325 feet. Although the county is drained into the Mississippi by two northwestward-flowing streams—South Fork of Forked Deer River on the northern border and the Hatchee across the southern half—the general surface does not slope to the northwest, but instead falls gently north or south toward one or the other of these two streams. The divide between them is low and undulating and runs east and west, passing through Brownsville. Stream cutting is nowhere deep, for the stream slopes, and consequently stream velocities, are uniformly slight. Another consequence of the absence of abrupt ravines is that springs are rare and usually weak and worthless.

Geology.—The entire county is underlain by the Lagrange formation, which is reached in wells at depths rarely greater than 25 to 50 feet, but which seldom are exposed in natural cuttings, the stream

valleys being so shallow. Over the Lagrange are 10 to 20 feet of Lafayette red sand or sandy clay, covered by 5 to 12 feet of light-colored loam that westward from Brownsville rapidly assumes a loess-like character, so that in a few miles it might very properly be called loess.

Water resources.—Springs are few and weak, and as a source of water supply are practically negligible. During dry weather they fail entirely. The numerous small streams that flow freely during the winter also go dry during the summer and autumn. Artificial ponds or deep wells are used for watering stock. The domestic supply is obtained from cisterns, ordinary wells, and deep wells, and the latter are rapidly coming into use also for industrial purposes. Most of the deep wells are of about 2-inch diameter, but vary considerably in depth. Perhaps a majority are between 80 and 150 feet deep, but some go 225 or 250 feet. The difference in depth is partly attributable to differences in surface elevation, those on hills going deeper than those on lower ground, and partly to differences in texture of the sands, which may make it necessary to go to considerable depths after water is reached before sand coarse enough to be checked by a strainer is found. All the wells are in Lagrange sand and, except where lignitic beds are encountered, furnish, as a rule, good, soft water.

At Belle Eagle water is obtained from springs and ordinary open wells, some of which reach 70 feet in depth.

Brownsville, on the divide between the two main drainage systems of the county, has an elevation of 344 feet. Previous to the introduction of a system of waterworks private wells and cisterns furnished the water supply. In the western part of town wells averaging 30 or 40 feet in depth gave good water and were exclusively used. In the eastern part of town wells are 80 feet deep, though water is not always obtained at that depth even, and the water is of only fair quality owing to mineral matter contained in it. In this part of town cisterns are largely used. Since the introduction of waterworks many have abandoned their wells and cisterns and use the town water. This is obtained from two wells 6 and 8 inches in diameter, respectively, each 230 feet deep. They were originally only 116 feet deep, but the sand at that depth was so fine that it entered through even the finest strainer slots and rapidly cut out the pump valves. By deepening to 230 feet coarser sand was found. The water is raised by air lift into a reservoir, whence it is forced either into a tank that gives a service pressure of 45 pounds, or directly into the mains under about three times this pressure for fire purposes. By the air lift 500,000 gallons per day can be pumped. The average daily consumption is 150,000 gallons. There are two pumps for forcing into the tank or mains of 500,000-gallon capacity each. The water is

very good for general purposes and for boiler use, though it forms a small amount of hard scale. No log or analysis could be obtained. According to one statement it rises to within 30 feet of the surface; to another, 47½ feet. The latter is probably the more accurate.

The electric light and ice company has a well 130 feet deep, but the water foams in boilers and is used only for the ammonia condensers. Town water is used for the boilers.

Blackwell's lumber mill has a 2-inch well 138 feet deep that is used for supplying the boilers. The water rises to within 45 or 50 feet of the surface. The log, from memory, is as follows:

Log of well at Blackwell's lumber mill, Brownsville, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand and clay (Lafayette and Columbia)	50	50
Sand	4	54
Clay, blue, tough	76	130
Sand, coarse, gray	8	138

Chester's Hardwood Lumber Company has a 3-inch well 109 feet deep, with the surface of the water at the same level as in the Blackwell well. Its log is as follows:

Log of well of Chester's Hardwood Lumber Company, Brownsville, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	15	15
Clay, blue	70	85
Sand, with some clay	15	100
Sand, coarse	9	109

The ground-water level is about 45 feet below the surface in these wells, and the largest element of uncertainty and the one on which the depth of the well in any given case here or elsewhere in town chiefly depends is the depth to sand coarse enough to be kept out of the strainers.

At Dancyville there are no springs of consequence. Wells are from 40 to 100 feet deep. Blue mud is often struck, and the water from it is poor, but when it can be obtained in the sand above the blue mud it is of better quality. Cisterns are largely used. Two miles west of town a 2-inch well was sunk through sand and clay 60 feet into a water-bearing sand that grew coarser to the bottom at 130 feet. The water is soft and is raised by a windmill.

At Eurekaton there are no springs or shallow wells except along the creek or river bottoms. Upland wells range from 75 to 125 feet in depth.

At Forked Deer there are only a few springs, and wells 40 or 50 feet deep yield very hard water. Good, soft water is obtained at depths of 100 or 150 feet in sand beneath blue clay. The log of Mr. J. W. Pearson's well is as follows:

Log of Pearson well, Forked Deer, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand and clay (loess?)	40	40
Sand, water bearing (Lafayette)	5	45
Clay, blue	95	140
Sand, coarse, water bearing, entered	10	150

At Ged open wells are chiefly used and run 25 to 40 feet deep, getting water from about the base of the Lafayette, or close beneath it. The water is generally soft, though in some wells it is hard owing to the loess-like surface loam. A number of 2-inch wells have been sunk to 80 feet in sand that becomes coarser until at that depth a strainer can keep it out. Half a mile away Mr. Columbus Hinkle has on high ground a 2-inch well 247 feet deep. The water is soft, rises to within 60 feet of the surface, and is used for boiler purposes. The blue clay shown by the log is found over much of the county, and has in many places just above it a bed of lignite several feet thick. The log is as follows:

Log of Hinkle well, Ged, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and sand, variegated, mixed	60	60
Sand, fine, with water	18±	78±
Lignite	4	82
Clay, blue (to 240 feet from surface)	158±	240±
Sand, coarse, gray, water bearing (penetrated)	7	247±

Two miles east of Ged a well being driven for Mr. Jim Livingston had the following log:

Log of Livingston well near Ged, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand and clay	20	20
Sand	30	50
Sand, quick	20	70
Lignite	4	74
Clay, blue	186	260
Sand, water bearing, thin, just entering	....	....

At Hanley there are no springs. Water is obtained from ordinary open and small pipe wells. It is generally good.

At Harvey there are a few small springs of no consequence. The water supply is from ordinary wells averaging 65 to 70 feet and deep or bored wells 100 to 125 feet deep. Water is good and soft.

At Jones, elevation 325 feet, an abundance of water rises nearly to the surface from a depth of about 75 feet.

At Keeling there are no springs. Wells, either open or small pipe, furnish soft water and range from 30 to 60 feet in depth. In one well 96 feet deep the water rises within 46 feet of the surface.

At Koho there are numerous springs and wells averaging in low places 20 feet deep.

At Rein, elevation 364 feet, water is obtained from dug or bored wells that range from 25 to 100 feet in depth.

Near Rudolph, in the edge of the Forked Deer bottom, a 2-inch well for the Hatchie Lumber Company passes through tough alluvial clay 32 feet, fine sand 5 feet, lignite 4 feet, blue clay 24 feet, coarse sand with soft water 5 feet.

At Stanton Depot, elevation 290 feet, water is obtained from small pipe wells that average about 140 feet in depth. The town well has the following log:

Log of town well at Stanton Depot, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand and clay	40	40
Sand	4	44
Clay, blue	96	140
Sand rock, soft	$\frac{2}{3}$	$140\frac{2}{3}$

When the 8-inch indurated layer had been penetrated the water rose within 40 feet of the surface. No lignite was obtained in this well, but in the others less than a mile away it was found. A well less than 100 yards from the town well found no blue clay, but only sand with a small amount of clay. A dozen or more of these small deep wells have been made in the immediate neighborhood and they all present about the same features.

At Tibbs there are no springs. Wells average 35 feet in depth and perhaps a third of them furnish a scant supply of water.

At Wellwood there are both dug and bored wells that vary in depth from 12 to 96 feet. The water from the shallow wells is inclined to be hard, that from the deeper ones soft.

HENDERSON COUNTY.

Topography.—Henderson County is situated near the eastern margin of the area discussed and its northern boundary is about midway between Kentucky and Mississippi. The area is 515 square miles. The divide between Tennessee and Mississippi rivers crosses the

county from north to south. The drainage of the western third goes to the Mississippi and that of the rest to Tennessee. The surface along this divide reaches an elevation of about 600 feet in a number of places, but along the streams it is considerably lower. The average elevation is about 500 feet. The lowest point in the county is probably where Beech River crosses the eastern boundary at an elevation close to 360 feet. South Fork of Forked Deer River, however, crosses the western boundary at only a few feet higher, and the Big Sandy crosses the northern boundary at slightly less than 400 feet. Big Sandy and Beech rivers and important branches of Forked Deer and Obion rivers all rise in the county and flow out radially. With their tributaries they have cut much of the surface into hills. Along the main divide and in much of the eastern slope the surface is very hilly. The streams have considerable fall and so have rapid currents and are actively eroding the surface.

Geology.—The formations found in this county include the Eutaw, Selma, Ripley, Porters Creek, Lagrange, and Lafayette.

The western edge of the Eutaw formation extends just slightly into the eastern part of the county. It dips to the west and passes beneath the other formations so that it underlies the entire county.

The Selma clay forms a belt 4 to 9 miles wide, extending north and south immediately west of the Eutaw outcrop. Its western edge is a few miles east of Lexington. The leaden and darker colored clays and marls characteristic of this formation are exposed in numerous railway cuts between Warrens Bluff and Darden.

The Ripley sands cross the center of the county from north to south in a belt 6 to 10 miles wide. They are distinguishable from the overlying Lafayette sands chiefly by their lighter color and their softer nature. Exposures occur in the deeper stream and railway cuttings.

A belt of typical leaden-gray Porters Creek clay, 3 to 5 miles wide, lies next west of the Ripley, and is succeeded in turn by the Lagrange, while over all the Lafayette is spread, as usual, in a thin veneer.

The exact thickness of no one of these formations in this county is known exactly. From the log of the Lexington well (p. 88) the Eutaw, the Selma clay, and perhaps half of the Ripley have an aggregate thickness of 500 feet, of which the upper 200 feet are probably Ripley. The Porters Creek must be not far from 100 feet thick. The Lafayette probably never reaches more than 20 or 30 feet.

Water resources.—There are many good springs among the hills that flow with undiminished volume the year round and feed the numerous streams, so that during summer they do not fail. Water for stock is obtainable almost everywhere, and some of the streams have fall and volume enough to furnish power for small mills. Where springs are not convenient for domestic purposes, water may be

obtained at depths of 50 feet or less in many places, and only in rare cases is it necessary to go deeper than 100 or 125 feet. Water obtained from the Eutaw, Ripley, or Lagrange sands is, as a rule, good and soft, though it may have, especially if from the Eutaw, some iron or iron and sulphur. Water from either the Selma or the Porters Creek is almost certain to be hard and of deficient quantity. It may in addition be flat and insipid, and in some cases is foul smelling and entirely unfit for use. Neither of these formations is very thick in this county, and if one is struck before a supply of water is obtained it should be bored through—probably less than 100 feet additional—and the underlying sand tested. Water will almost certainly be obtained and will probably be of good quality and quantity. Cisterns are used to some extent in the area of the Selma clay and the Porters Creek clay and in other areas, where, because of the local elevation the depth to underground water is inconveniently great, say 75 or 100 feet or more.

At Atkins water is obtained from ordinary wells and an occasional spring.

At Crucifer, in the Lagrange area, there are only ordinary wells that range from 20 to 85 feet deep according to elevation. There are a few springs.

At Darden, elevation 392 feet, near the western edge of the Eutaw sand, some bold springs in low places flow from the Eutaw, but the chief supply of water is obtained from wells that range from 15 to 75 feet in depth. The water in the deeper wells is good and soft and rises somewhat in the well.

At Dolen weak flows are obtained from pipe wells in the Selma clay—there called simply "black dirt"—at ordinary depths. The water is hard and in some wells it also contains alkali or alum. Small pipe wells or even 6 to 12 inch bored wells should be sunk easily through the Selma clay and get good water from the underlying Eutaw sand.

At Farmville there are a few springs and numerous ordinary dug and bored wells, some of which are 80 feet deep. The water is soft, but the quantity is not always large.

At Hinson Springs, elevation 440 feet, there are several chalybeate springs flowing from the Ripley sands, that are discussed on page —.

At Huron, elevation 416 feet, there are a few springs and cisterns and wells from 30 to 60 feet deep that furnish soft water.

At Law, in the Lagrange sand area, wells furnish soft water from sand under pipe clay at an average depth of 50 or 60 feet, the range being from 20 to 85 feet.

Lexington, in the Ripley sand area, elevation 484 feet, has no system of waterworks, but depends on individual wells for its water supply. These wells average 50 or 60 feet in depth. Some on high

ground are 80 feet deep. The quality of the water is good. No cisterns are used.

The Nashville, Chattanooga and St. Louis Railway finished in February, 1903, a well 700 feet deep that has not been a success. The driller gave the following log from memory:

Log of well of Nashville, Chattanooga and St. Louis Railway, Lexington, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand, with shells of soft sand ironstone 6 or 8 inches thick scattered through it, and a little clay, water in all below first 50 or 60 feet (Lafayette and Ripley)	200	200
Clay, blue, with a little water-bearing sand and gravel at the bottom (Selma and Eutaw)	300	500
Limestone, pure, no chert (penetrated)	200	700

At 700 feet the well was abandoned. At 675 feet water was struck that rose within about 80 feet of the surface, but the quantity was considered insufficient. The writer believes that with proper management this well would have been a success and yielded all the water needed by the railway. Either of two parts of the section gone through would have yielded a supply of water that would have risen within 75 or 100 feet of the surface. The elevation of Lexington and the nearness and elevation of outcrops of these two water-bearing beds to the east are such that there was no chance to get a flowing well. The driller was not familiar with drilling in soft strata, did not know how coarse sand had to be in order to be kept out by a strainer, and so passed through the Ripley sand without testing it. When the basal sand and conglomerate bed of the Eutaw beneath the blue clay was reached, it was found to be quicksand, and although the water rose probably within about 100 feet of the surface, sand also ran in rapidly, and the water was not tested, but the casing was driven down to the limestone below in order to shut it off. When this had been done practically all hope of getting a successful well had vanished. Had the conditions of drilling in sand and clay been more perfectly understood the well very probably would have been finished successfully, either in the Ripley sand, at a depth of 200 feet or less, or, at the farthest, in the coarse water-bearing sand and cobbles at the base of the Eutaw at 500 feet. The Ripley water would have certainly been a good boiler water, and very probably the Eutaw water would have been good also.

At Life, elevation 520 feet, there are some springs near the streams. Wells average 75 feet in depth, but some go to 100 or 120 feet.

At Long there are a number of ordinary wells 60 to 70 feet deep that yield a soft water of small quantity.

At McHaney water is obtained from springs and ordinary wells, all being freestone.

Middlefork is on the ridge dividing the Mississippi and the Tennessee drainages. It is in the Ripley sand area, in which good soft water is obtained, but the wells are mostly bored and have an average depth of 120 to 140 feet. In low places a few shallow dug wells are in use and good springs occur along the streams.

At Pipkin there are several wells from 10 to 40 feet in depth and a great many springs.

At Reagan poor water is obtained from the Selma clay by shallow open or deeper bored wells. Cisterns are largely used.

At Safford water is obtained from shallow wells.

At Spellings there are numerous springs and shallow wells.

At Whitefern there are numerous springs, some of which are chalybeate. Wells are generally used, however, for domestic supply. Water of good quality is abundant at depths of 18 to 30 feet.

At Wildersville, elevation 476 feet, in the Ripley sand area, freestone water is obtained from wells that average about 50 feet deep.

HENRY COUNTY.

Topography.—Henry County lies on the eastern edge of the area discussed. It is bounded by Kentucky on the north and by Big Sandy and Tennessee rivers on the east. The area is 625 square miles. The Tennessee-Mississippi divide crosses the middle of the county in a direction somewhat east of north. The surface along this divide is rough and broken. On the east it has a relatively steep slope toward Tennessee and Big Sandy rivers, but becomes somewhat less hilly, though stream activity on the Tennessee side is more marked than on the other side. West of the divide the general surface at first has a considerable slope, but soon flattens out into a nearly level plain that stretches westward to the Mississippi bluffs. The greatest elevation is slightly more than 600 feet, along the divide in the northwestern part of the county. The least elevation is about 300 or 305 feet, at the point where Tennessee River leaves the State. The average elevation of the county is about 500 feet, though some portions depart materially from this average. The drainage of the eastern slope is largely to the Big Sandy; that of the western into the headwaters of the various branches of the Obion.

Geology.—A strip a few miles wide along Big Sandy and Tennessee rivers on the eastern edge of the county belongs to the Paleozoic area, and is not considered here. West of this strip the county is underlain by the Ripley, Porters Creek, Lagrange, and Lafayette formations.

The Ripley sands overlie the Paleozoic limestones in a belt averaging 5 miles in width, which crosses the eastern part of the county from north to south and dips westward beneath the Porters Creek clay. The latter formation lies next west of the Ripley in a belt

about 3 or 4 miles wide, also running north and south. Its western edge is at Paris, where it may be seen dipping westward and passing under the Lagrange, which underlies the remaining half of the county and has its usual character. Over all there is a deposit of 10 to 20 feet of Lafayette, chiefly a red sand, but with some small gravel at its base in places. There are also here and there above the typical Lafayette sand a few feet of light-colored, softer, sandy loam that may represent the Columbia.

Water resources.—In the Ripley area springs are numerous and strong, and furnish pure water. In the Lagrange area they are of the same character, but somewhat less numerous, because surface erosion has not produced as great diversity of relief there as in the Ripley area. In the Porters Creek clay belt they are scarce, weak, and poor as a rule. The streams are numerous and usually have a permanent flow. Many of them have sufficient volume and fall to furnish power for mills. Underground water of good quality is available at moderate depths anywhere within the embayment part of the county. In the western half it may be obtained from the Lagrange sands at depths rarely exceeding 100 to 150 feet. In the Porters Creek clay belt or just west of it, on the thin eastern edge of the Lagrange, good water may be had from the underlying Ripley by going through the Porters Creek, as has been done in the town wells at Paris. In such wells the water will rise part way to the surface. In the Porters Creek area, where the surface water is poor, and in elevated parts of the Lagrange and Ripley areas, where the distance to underground water is several score feet, cisterns are much used.

At Buchanan soft water is obtained from the Ripley at depths of 75 to 80 feet.

At Como, in the Lagrange area, there are no springs. Dug and small bored wells are used.

At Cottage Grove, in the Lagrange area, soft water is struck at depths of 75 to 100 feet. About half the people use cisterns.

At Eastwood, near the contact between the Porters Creek clay and the Lagrange sands, there are some springs of good water, but wells drilled 80 or 90 feet deep get hard iron and sulphur water from the Porters Creek clay, or "soapstone." They should be drilled somewhat deeper, to the Ripley sand.

At Freeland the Ripley sand is the surface formation. Soft water is obtained from springs and from open and bored wells of an average depth of about 40 feet.

At Hastings, in the Lagrange area, there are springs and ordinary and bored wells 30 or 40 feet in depth. The water is soft.

At Mansfield, elevation 448 feet, in the Ripley area, soft water is obtained from shallow open and bored wells.

At Mountvista, in the Ripley area, soft water is struck at depths of 60 to 80 feet. Wells are open or bored.

At Nobles wells are from 40 to 70 feet deep. The water in the shallower wells seems to be hard and in the deeper ones soft. No records of strata encountered were obtained, but possibly the shallower are in the Porters Creek clay and the deeper in the Ripley sand.

At Osage soft water is obtained from the Lagrange sand at depths of 100 to 150 feet. Cisterns are used generally.

At Owens Hill, in the Ripley area, soft water is obtained at a depth of 16 feet in low places and of 75 or 80 feet on the upland level.

Paris, elevation at Nashville, Chattanooga and St. Louis depot 512 feet, at Louisville and Nashville depot 474 feet, is on the eastern edge of the Lagrange. The Porters Creek clay is exposed in the deeper cuttings. There are a few cisterns in use, and ordinary wells get water from near the base of the Lagrange at an average depth of 30 to 60 feet. A large spring near town is reported to flow 300,000 gallons per day. The city waterworks has two wells, one 8 and the other 6 inches in diameter, each 376 feet deep. The elevation of the well heads is 470 feet and water stands 70 feet below the top. Water is raised by air lift into a surface cistern, from which it is forced into a steel tank of 70,000 gallons capacity, that gives a service pressure of 35 pounds. For fire purposes a direct pressure of 100 pounds, or more if necessary, is used. The capacity of the pumps is 500,000 gallons per day; the average daily consumption, 150,000 gallons. The water is perfectly clear, and is good for all purposes. After standing, a slight red ferruginous deposit forms and discolors vessels. The following analysis was reported by the St. Louis Sampling and Testing Works May 14, 1902:

Analysis of water from well at city waterworks, Paris, Tenn.

	Parts per million.
Silica (SiO_2)	3.6
Oxides of aluminum and iron ($Al_2O_3+Fe_2O_3$)	9.2
Calcium (Ca)	5.7
Magnesium (Mg)	3.4
Sodium (Na)	1.5
Carbonate radicle (CO_3)	9.6
Sulphate radicle (SO_4)	8.9
Chlorine (Cl)	4.4
	46.3
Volatile solids	14.4
Fixed solids	44.0
Total solids	58.4

At Peryear, elevation 612 feet, in the Lagrange sand area, soft water is obtained at depths of 100 or 115 feet.

Routon, elevation 575 feet, is in the Lagrange area. Small bored wells are commonly used, ranging from 60 to 90 feet in depth, and furnishing a moderate amount of soft water of fine quality.

At Vandyck, elevation 416 feet, on the eastern edge of the Porters Creek clay, wells average about 40 feet in depth. One, 87 feet deep, is a blowing well whenever the weather is changing. The springs are described as being weak and impregnated with sulphur, iron, and alum. They very probably flow from the Porters Creek formation.

LAKE COUNTY.

Topography.—Lake County is situated in the northwest corner of Tennessee. It lies between Reelfoot Lake on the east and Mississippi River on the west. Its length, north and south, is about 35 miles. Its width, east and west, varies from 3 to 12 miles. It is one of the smallest counties in the State, the area being 128 square miles. The entire county is situated in the alluvial region of the Mississippi and the surface is very level, with neither hills nor ravines. The county is so low that about two-fifths of the surface is overflowed at high water. The average elevation is about 300 feet. The general surface slope is southward, in conformity with the river slope, the elevation being about 315 feet on the northern line and 290 on the southern.

Geology.—The surface formation is everywhere the alluvium of the Mississippi flood plain. The geologic relation and age of this alluvium have been discussed somewhat fully on page 48, and need not be treated here. From the records of the few borings that have penetrated the alluvium, it would seem to be from 100 to 150 feet deep. Beneath it lies the Lagrange, but so far as known it has not been explored by deep borings in this county.

Water resources.—There are no streams in the county except the sloughs from the river or Reelfoot Lake. Ponds are easily made for watering stock, and cisterns and shallow wells are used for domestic supply. The well water is of the usual unsatisfactory alluvial-region type, and is obtained at depths of 20 to 35 feet.

At Hathaway water is obtained from Mississippi River and from wells that average 35 feet in depth. The water in the wells rises and falls with the river.

At Keefe shallow pumped wells are used.

At Madie hard water is obtained from open and pumped wells that average 25 or 30 feet in depth.

At Ridgeley water is obtained by pumping from driven wells about 25 feet in depth. The water is hard, and contains iron sulphate or copperas.

LAUDERDALE COUNTY.

Topography.—Lauderdale County is bounded by Mississippi River on the west and lies midway between the northern and southern

boundaries of Tennessee. Its area is 460 square miles. The western half of the county and a narrow area along Hatchee River on the southern boundary belong to the alluvial plain of the Mississippi and its tributaries, and so are low and level, in part swampy. The remainder of the county rises from the flood-plain level, usually by abrupt bluffs, to a general elevation of about 350 feet. The edges of the upland or plateau surface adjacent to the alluvial region are deeply cut by streams, and the resulting hills are steep and bold. Elsewhere the plateau surface is level or gently rolling. Along the principal streams a second bottom or terrace is usually developed, rising 10 to 20 feet above the present flood plain, and reaching in places a width of several miles. The drainage all passes through the Forked Deer and the Hatchee to the Mississippi.

Geology.—The formations represented in the county are the Lagrange, Lafayette, loess, and alluvium.

The Lagrange is rarely exposed except along the lower parts of the steep bluffs and in occasional deep railway cuts, as at Ripley (see p. 43) and Curve. The section in the long, deep cut just south of the station at Curve shows at the base 15 to 18 feet of a dark-blue lignitic clay bedded in very thin layers and somewhat sandy. Over it lie 6 to 9 feet of a yellow to rusty-yellow purer clay, also lignitic, covered by 25 feet of Lafayette sand and gravel. The gravel is well rounded chert and vein quartz, averaging 1 inch or less in diameter, but with occasional pebbles reaching 2 or 3 inches. The gravel is in irregular streaks throughout the formation and composes about 20 per cent of it. The sand is coarse and red and is case-hardened, so that it stands with vertical faces. Over it is a variable layer of soft, light-colored sand and gravel up to 3 feet thick. This grades up into 25 feet of loess, which seems hardly separable into a lower and an upper division, though the lower 5 or 6 feet are darker than the remainder. Beneath the dark Lagrange clay in the bottom of the cut is a quicksand, on which the track rests, and which is a perpetual source of trouble and expense to the railway. A view of the section in the cut is given in Pl. IV, *A*, p. 44.

The Lafayette in Lauderdale County is a coarse sand, with a considerable proportion of pebbles as a result of the nearness of Mississippi River. It overlies the Lagrange everywhere except in the alluvial region, where it has been removed by stream erosion. It is exposed in only a few places, being, as a rule, overlain and concealed by the loess, which varies from 1 foot to several score feet in thickness. The loess mantles the uplands and seems to extend down over the second bottoms along the main streams, though the observations of the writer were not full enough to settle this last point definitely.

Water resources.—There are many streams in the county, so that it is generally well watered. For domestic purposes cisterns have

long been widely used, because of the hardness of the water from shallow wells, which almost invariably stop in the lower part of the loess. Such wells are, however, used in many places despite the hardness of the water. Water that is generally, though not invariably, soft and good may be had usually at depths of 100 to 300 feet, the depth varying chiefly with the texture of the sand, though in some cases it is determined by the occurrence of sandy clay beds, which in this region are generally lignitic and furnish a poor quality and small quantity of water. The wells may go down several hundred feet in exceptional instances, as at Ripley, for example. At the foot of the steeper bluffs springs occur, but the water is usually hard and has an unpalatable taste, commonly described as "sweet."

The shallow water in the alluvial region is always poor, and brick cisterns are difficult to keep from cracking because of the soft, yielding nature of the alluvial deposits. It would seem that in this region cisterns should be built of cypress, but so far as known this wood has never been used for that purpose.

At Arp water is obtained from springs at the foot of the hills and from dug and bored wells 20 to 30 feet deep. The hills rise perhaps 75 feet high and on the top of one a well was bored 208 feet and abandoned without getting water. Some water was found in the base of the Lafayette, but the quantity was thought insufficient. The following is the log:

Log of well at Arp, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay (loess)	50	50
Sand and gravel (Lafayette)	34	84
Blue sandy loam and streaks of lignite	66	150
Blue sandy clay (penetrated)	58	208

At Ashport, on the Mississippi, a number of small tubular wells about 50 feet deep yield hard water. They go through about 8 feet of surface loam into sand mixed with some gravel, which soon becomes water bearing. At 30 feet from the surface this gives place to a coarse blue sand that runs to 52 feet and is underlain by gravel, which was not explored.

At Bexar a well drilled 135 feet deep got a good supply of water that rose about 15 feet in the pipe. The log was as follows:

Log of well at Bexar, Tenn.

	Thickness.	Depth.
	Feet	*Feet.*
Yellow clay (loess)	35	35
Sand and gravel (Lafayette)	4	39
Sand, white, coarse, with a little gravel	12	51
Gravel	8	59
Sand, white, with a number of 3 or 4 foot layers of gravel in it	42	101
Sand, water bearing, but without pressure	19	120
Gravel	10	130
Clay, blue	$\frac{1}{3}$	$130\frac{1}{3}$
Sand, white, with water, which rises about 15 feet	4	$134\frac{1}{3}$
Clay	Streak.	....
Gravel (not explored).		

At Double Bridges both wells and cisterns are used. Wells vary from 20 to 100 feet deep and many of them are bored. Quicksand occasionally interferes with borings. The quality of the water is usually fair to good.

At Dry Hill cisterns are generally used. Wells on the hills obtain soft water at depths of 100 feet or more.

At Edith, on the edge of the bluff overlooking the Mississippi flood plain, cisterns are used almost exclusively. Water from shallow wells is hard and sweet. It is also found at about 150 feet, and there are three deep wells 2 or 3 inches in diameter and 165 feet deep. Two are at mills, and are pumped by steam. The other is pumped by hand. They furnish an abundant supply of water, said to be alkaline and to have a diuretic effect. The log is as follows:

Log of deep wells at Edith, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay (loess)	80	80
Sand and gravel, red, in alternate layers each 3 to 4 feet thick (Lafayette)	20	100
Sand in yellow and white streaks, dry	50	150
Sand, same, water bearing	15	165

At Fulton cisterns are used almost entirely. There are one or two wells about 75 feet deep, but the water is hard.

At Gates, elevation 321 feet, water is obtained from both cisterns and shallow wells that average 30 to 45 feet in depth and furnish hard water. A well drilled 114 feet gave the following log:

Log of deep well at Gates, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	8	8
Blue mud	15	23
Clay, blue, stiff	15	38
Sand and gravel	10	48
Blue mud	52	100
Sand, with water rising within 30 feet of the surface	14	114

At Glimp water is obtained from cisterns and common wells 25 to 50 feet deep.

At Halespoint, on the Mississippi flood plain, there are only shallow wells that yield the usual poor flood-plain water.

At Halls, elevation 312 feet, water is obtained from cisterns and from a few wells drilled to about 160 feet, where a water-bearing sand is found. There is pressure enough to raise the water within 30 feet of the surface.

At Henning, elevation 292 feet, hard water is obtained from dug wells that average about 40 feet deep.

At Mack water is struck at depths of about 20 feet and 80 or 90 feet. Water from the latter depth rises about 25 feet. All of the water is hard, and that from the deeper wells contains some iron.

At Ripley, elevation 390 feet, there were formerly many wells that averaged about 85 feet deep, some of which gave soft water, while others gave hard. Cisterns have since been almost entirely substituted for them. Around the foot of the bluffs near town are numerous springs, most of which yield hard water. The town system of waterworks is supplied by three wells about 10 feet apart, two being 6-inch, the other 4-inch, and each being 100 feet deep. The water is hard and produces a hard scale when used in boilers. It stands at 65 feet from the surface, and the wells yield 150,000 gallons a day.

At Tams Landing, on Mississippi River, a mile below Halespoint, there are alternating beds of sand and gravel that have been explored to a depth of 84 feet. Hard water is struck at 21 feet.

MADISON COUNTY.

Topography.—Madison County lies just south of the center of the embayment area of Tennessee and has an area of 545 square miles. The county belongs to the Mississippi drainage basin and so slopes slightly to the west or northwest. The surface in the eastern, southeastern, and southern parts of the county is considerably broken. The central part of the county is rolling, and the western, northwestern, and northern parts are more nearly level. On the ridges between the main streams the surface rises to an elevation of about 500 feet and, while there is considerable difference in relief between various parts of the county, the average elevation is about 450 feet. The highest points are in the southeastern part of the county and are between 500 and 550 feet. The lowest point is about 315 feet, where South Fork of Forked Deer River leaves the county.

Geology.—The formations of the county are the Porters Creek, the Lagrange, and the Lafayette.

The Porters Creek clay occurs along the southeastern edge of the county, south of the point where the Nashville, Chattanooga and St. Louis Railway enters it. This clay outcrops in a belt from 4 to 6

ARTESIAN WELL AT JACKSON, TENN.

miles wide, of which only the western half lies within the county. The Lagrange succeeds it to the west and underlies all the rest of the county, but is largely concealed by the red or orange sands of the Lafayette, which averages about 20 feet in thickness and forms the surface except where removed by stream erosion.

Water resources.—The streams of the county are numerous and the longer ones flow perennially. Many of the smaller streams become very low and sluggish or go dry altogether during late summer and fall. In localities where streams fail ponds are provided for watering stock. Springs occur along the foot of the hills and are used to some extent, but the principal water supply comes from wells in the base of the Lafayette or the top of the Lagrange sands. This water is freestone, but in the small Porters Creek area in the southeastern part of the county the water is poor and hard when the well is made in the dark clay of this formation. Water of good quality and quantity should be obtained in deep wells anywhere in the county. In the western part it would come from the Lagrange sands. In the eastern part, within the Lagrange area, it might still in many places be obtained from the base of the Lagrange at depths of 100 to 150 feet, or from the Ripley sands beneath the Porters Creek clay at depths of 150 to 200 feet additional. It seems most probable that the deep well at Jackson (see p. 98; also Pl. V) ends in the Ripley sand. Such an interpretation would make the Ripley include in the Jackson section a clay bed containing shark's teeth, but this formation is nowhere in surface exposure in Tennessee known to contain such a bed. Marine fossils occur in it in Mississippi, however, only a short distance south of the Tennessee line. One alternative supposition, that the 72 feet of fossiliferous dark lead-colored clay is Porters Creek, gives that formation an abnormal thickness of 288 feet. The other alternative supposition, that this bed represents the Selma clay, makes that formation only 72 feet thick and the Ripley sand above it only 41 feet thick—both of which would be abnormally thin, the Ripley especially so.[a]

At Andrews Chapel water is obtained from wells that run usually from 50 to 60 feet deep, but are exceptionally 100 feet deep.

At Beechbluff, elevation 396 feet, water is obtained from springs and from wells of 20 or 30 feet depth. Much of the water contains iron and sulphur.

At Carroll, elevation 369 feet, wells average 18 to 40 feet deep; in

[a] Since the above was put in type the writer has had an opportunity to examine a partial set of borings from the Jackson deep well and also some notes made while drilling was in progress. From these it seems that the base of the Lagrange is at 157 feet depth; the Porters Creek extends from 157 to 335 feet; the Ripley sand from 335, probably to 405, feet; the Selma clay probably from 405 to 499¼ feet, and the Eutaw from there down. There is some uncertainty as to the upper and lower limits of the Selma clay, but the section from 405 to 438 feet seems without doubt to belong to it. This will modify and explain somewhat the section of this well given on page 98. The well shows an electric current of about half a volt.

the surrounding country they are from 40 to 150 feet deep. The water is soft. In some cases the quantity is reported as insufficient.

At Catalpa there are some springs and good water is obtained from wells that range from 20 to 60 feet in depth.

At Claybrook soft water is procured from wells that average 60 feet in depth.

At Hatchie, elevation 328 feet, soft water is obtained from pumps and open wells ranging from 15 to 40 feet in depth.

At Jackson the elevation of the ground at the crossing of the Illinois Central and the Mobile and Ohio railroads is reported to be 425 feet, of the mark at the Federal building 394 feet, and of the Nashville, Chattanooga and St. Louis depot 340 feet, though this last figure would seem to be too low. Water is obtained in shallow wells at a depth of 30 to 50 feet, depending on the surface elevation. A battery of 22 wells of the city water company drew 1,000,000 gallons daily at a depth of 40 feet, while another group of 18 of these wells now yields about 2,500,000 gallons daily from a second water-bearing sand at a depth of about 100 feet. The pores of the sand become clogged after a time and are flushed out by forcing a current backward into it. The shallower wells yield water that forms a coating of oxide of iron in the pipes. The water from the deep well already mentioned dissolves and loosens up this deposit so that it comes out in small particles and makes the water for the moment a blood-red color. The deep-well water on standing some hours gives off CO_2 and becomes opalescent while a flocculent precipitate of iron is forming. This iron soon settles and leaves the water once more clear. The wells in the water-bearing stratum at 90 to 100 feet below the surface have a galvanic current of one-fourth to one-half volt, due probably to the corrosion of the copper in the strainer by the sulphuric acid resulting from the decomposition of the iron pyrite. Lead pipes, if grounded by a copper wire, are eaten up by electrolysis in about eighteen months. The log of the deep well is as follows:

Log of deep well at Jackson, Tenn. [a]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay, sandy, red (Lafayette)	12	12
Clay, tough, blue	16	28
Sand, coarse white	12	40
Clay, snow white, very tough	6	46
Sand, nearly pure white, some small gravel and thin ironstone crusts, water bearing at base	60	106
Clay, at top light colored, lower part variegated red, yellow, etc	43	149
Sandstone, dark brick-red, soft (base of Lagrange)	11	160
Clay, fine, leaden-colored (Porters Creek)	170	330
Rock, dark, hard (limestone?) (base of Porters Creek)	5	335
Sand, white, with water	13	348
Quicksand, white, very micaceous	28	376
Shales, dark leaden-colored, with hard streaks of micaceous sandy material, lignite fragments, and iron pyrite. At about 418 feet shark's teeth	72	448
Sand, white, water bearing	77	525
Hard material (not entered).		

[a] See, however, footnote on page 97.

At Leighton water is obtained from ordinary wells and from a 2-inch driven well that penetrated coarse sand to a depth of 75 feet, where the underground-water level was reached. The sand grew coarser to 120 feet, at which depth the well was finished.

At Malesus, elevation 453 feet, water is obtained from wells that average about 60 feet in depth, but range from 40 to 100 feet.

At Mercer, elevation 344 feet, water is obtained from a creek, from springs, and from wells ranging from 25 to 100 feet in depth, with an average of 40 feet.

At Neelys, elevation 504 feet, water is obtained at depths that range from 60 to 150 feet, the deeper wells being much more reliable. Pools are used for stock water.

At Norwood, elevation 448 feet, water is obtained at depths of about 80 to 100 feet. Pools are used for watering stock.

At Rollins bored wells about 100 feet deep are generally used.

At Springcreek there are small tubular and bored wells that range from 70 to 100 feet in depth.

M'NAIRY COUNTY.

Topography.—McNairy County is situated in the southeastern part of the embayment area in Tennessee. Its eastern edge almost reaches the Paleozoic rocks. Its southern boundary forms part of the Tennessee-Mississippi line. The area is 570 square miles. The eastern half of the county is crossed from north to south by the divide between Tennessee and Mississippi rivers, so that two-thirds of the county slopes westward and one-third eastward. The lowest point in this dividing ridge is at the head of Lick Creek, on the southern edge of the county, where the elevation is 520 feet. Just northeast of Purdy the ridge is about 600 feet high. The lowest point in the county is at about 345 or 350 feet elevation, where Rose Creek crosses its western boundary. The plateau surface of the county averages between 450 and 500 feet in height. The main divide north of Purdy is hilly. The eastern and southeastern parts are more nearly level. The southwestern and western parts, near the Hatchee and its tributaries, are broken and hilly.

Geology.—The formations of the county are the Eutaw, the Selma, the Ripley, the Porters Creek, and the Lafayette.

The Eutaw sand is found at the surface only in a small area in the southeast corner of the county, but as it dips westward it underlies all the other formations.

The Selma clay has a greater development, both in area and in thickness, in this county than elsewhere in Tennessee. The thickness varies from 350 feet in the southern part of the county to about 300 feet in the northern part. The width of the belt decreases from about 10 miles in the southern part to 5 miles in the northern part. Over much of this belt the Lafayette, which once covered it entirely,

has been removed by erosion, leaving the bare leaden-colored clay, greensand, and fossil shells exposed at the surface in areas many of which are of considerable extent.

The next formation to the west is the Ripley. It occupies all of the county west of the Selma clay belt except a few square miles of Porters Creek clay in the extreme northwest corner. The Ripley forms a prominent ridge that enters the State from Mississippi and extends a number of miles northward before it dies down and merges with the general plateau surface. A discussion of the origin of this ridge, as well as the section at the point where it is cut through by the Southern Railway in the "big cut" just west of Cypress, are given on page 29.

Water resources.—Numerous springs from the sands of the Eutaw and the Ripley flow the year round and feed streams that water every part of the county. From the high divide northeast of Purdy streams flow radially in almost all directions. Water from the Eutaw and Ripley, whether obtained by springs or by wells, is soft and generally free or almost free from iron and sulphur. Water from the dark clays of the Selma and Porters Creek is generally poor. For years it has been the custom in the Selma area to bore 6 or 8 inch wells 200 to 300 feet through the clay into the underlying Eutaw sand, the water in which rises in many cases nearly to the surface. In some places in these areas of poor water cisterns have been used, though not to so great an extent as in the tier of loess counties adjoining the Mississippi. Occasionally a pond for stock watering is found. Wells range from 20 to 70 feet in depth except in the Selma clay, where they may be from 200 to 300 feet deep.

Adamsville is on a plain or table-land between two creek valleys. The joint clay of the Selma reaches practically to the surface in some places; in others it is covered by 20 to 25 feet of Lafayette. Wells average 16 to 20 feet in depth and give soft or hard water according as they are in the Lafayette or the Selma.

At Acton water is obtained from ordinary open wells 30 or 40 feet deep. A number of springs yield iron and sulphur water that is used locally for medicinal purposes.

At Bethel Springs, elevation 459 feet, there are springs and numerous wells that average 30 feet deep but range from 20 to 40 feet. The water is impregnated with iron and sulphur.

At Caffey there are no springs; water is obtained from ordinary wells that have an average depth of only about 15 feet.

At Gravehill water is obtained chiefly from bored wells that go through the Selma clay and are between 200 and 300 feet deep.

At Leapwood, near the junction of the Ripley and the Selma, there are several large springs, some shallow wells, and a small well 360 feet deep.

At McNairy, elevation 449 feet, there are some springs and numerous wells that average about 35 feet deep. The water is soft and in many wells contains sulphur.

At Michie there are shallow open wells and good springs.

At Purdy, on the Mississippi-Tennessee divide, which is here a narrow plateau, many springs flow from the base of hills on either side. In the town, wells in the base of the Lafayette average about 30 feet deep, while those that enter the Selma clay go 200 feet or more before reaching the Eutaw sand.

At Selmer, elevation 460 feet, the supply is obtained chiefly from wells 20 to 80 feet deep. There are a few cisterns, and one well, 416 feet deep, gets water from the Eutaw sand. The casing goes down only about 50 or 60 feet. The water rises to within 30 feet of the surface and is slightly hard. The log is as follows:

Log of well at Selmer, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface sand and clay (Lafayette)	25	25
Clay, blue (Selma)	375	400
Sand, water-bearing (Eutaw) (entered)	16	416

At Stantonville the Lafayette is 35 to 40 feet thick, and has at the base several feet of rounded chert gravel in which water is abundant. Beneath it is the Eutaw sand, but this is somewhat quick and tends to fill up a well. A mile or less to the west the Selma clay is struck, and wells are bored 80 to 250 feet through it into the Eutaw sand below. The water rises in some places nearly to the top.

OBION COUNTY.

Topography.—Obion County is in the northwestern part of Tennessee. Its northern boundary is the State line, and its western boundary is the western shore of Reelfoot Lake. A part of the eastern boundary is formed by branches of Obion River. The area is 505 square miles. A narrow belt along the eastern shore of Reelfoot Lake and a belt for the most part several miles wide along Obion River are low and level and subject to overflow. On either side of this swamp belt of the Obion there is a level bench or second bottom 15 to 25 feet higher than the first bottom and, as a rule, several miles wide. The remainder of the county is more elevated and forms a part of the general upland or so-called plateau slope of western Tennessee. Its surface varies from rolling to abruptly hilly, especially along the western border, where the region is known as the lake hills. The lowest part of the county is the surface of Reelfoot Lake and the swamps bordering it. These have an elevation of about 260 or 270 feet. The highest point is probably in the northern part of the

county near the Mobile and Ohio Railroad, where the elevation is slightly over 400 feet. The average elevation of the upland is about 350 or 375 feet.

Geology.—The geologic formations of the county are the Lagrange, Lafayette, loess, and alluvium.

The Lagrange underlies the entire county, but is concealed, except here and there along the base and lower slopes of the lake hills, by one or more of the other formations, all of which are merely surficial. Drill records and an examination of the near-by exposures at Hickman, Ky., indicate that the Lagrange contains rather more clayey material in this region than in its type region in Fayette County. Water-bearing sands are, however, found in it, and wells are generally successful.

The Lafayette is found on the uplands only, and is 20 to 30 feet thick. The upper part is, as a rule, orange or yellow sand, while the lower part consists of well-rounded chert gravel. In some places the gravel and sand are interbedded. The gravel is more abundant near the river.

The loess mantles the Lafayette on the uplands and laps down over the second bottoms, where it lies directly upon the Lagrange. It has its usual character and is 20 to 80 feet thick in the central and western parts of the county, but thins out in the eastern part and practically disappears by merging into a surface loam a few feet thick, which is everywhere revealed in railway and other cuttings overlying the Lafayette.

The alluvium is confined to the Obion and Reelfoot swamps.

Water resources.—Along the sides of the stream valleys and among the hills springs are frequently found. Those in the swamps are sweet and many others are hard or contain iron and sulphur, so that, as a rule, they are not a valuable source of water supply. The springs feed numerous streams that during winter furnish water for stock in nearly all parts of the county, but during the summer all except the main branches of Obion River shrink away to a series of pools or go entirely dry. Ponds must then be relied on for stock watering. Wells generally reach water at comparatively shallow depths, usually in the Lafayette sand and gravel, but in the loess region this water is commonly hard. Deeper wells have been drilled in a number of places and get water from the Lagrange. In the loess region cisterns are largely used on the uplands, but on the second bottoms the loess or clay is so soft that it is often hard to keep the cistern from settling and cracking so as to let the surface water seep in, and in such places wells are used.

At Crockett, elevation 290 feet, there are small shallow wells and a number of springs.

At Elbridge there are only ordinary shallow wells and a few springs.

At Glass wells are usually 20 to 40 feet deep, and soft. One on

the river bottom is 96 feet deep, striking water at 90 feet that rose within 20 feet of the surface.

At Gratis and Guelph water is obtained from ordinary shallow wells and springs.

At Kenton, elevation 309 feet, wells on the hills generally yield fine water. Those on the bottoms are not so good and may fill almost full during wet weather. Along the bottoms are springs, most of which are impregnated with iron or iron and sulphur. The water in some of the wells is hard because of the loess; in others below this formation it is soft.

At Masonhall the wells range from 30 to 65 feet in depth. The shallower wells are in loess, and the water rises and falls with the seasons. The deeper ones are in the Lafayette sand. There are numerous springs.

At McConnell, elevation 354 feet, good water is struck at a depth of 30 to 40 feet.

Minnick is in the loess area, and has but few wells or springs. Cisterns are almost universally used. A 3-inch well started in a ravine on Lafayette sand and gravel, which it passed through at 50 feet and entered blue clay; this continued to a depth of 280 feet, and contained, at intervals of 10 or 15 feet, hardpans or indurated beds, slightly gritty, that averaged about a foot each in thickness. At 280 feet the blue clay changed to a gray clay, in which the indurated layers occurred at about 5-foot intervals. In this material, at a depth of 300 feet, the well was abandoned.

At Moriah water is obtained from springs and wells, some of the latter being 40 to 50 feet deep.

At Obion, elevation 289 feet, there are some shallow surface wells. Good water is obtained from sand at a depth of about 80 feet. It is generally soft and abundant.

At Polk, elevation 330 feet, there are no springs, wells and cisterns being used. The wells are generally hard and average about 30 feet deep. A few are 40 or 50 feet deep.

At Rives, elevation 295 feet, there are a few cisterns, but the black clay loam in which they are dug is not firm enough to keep them from cracking. Shallow wells with water of only fair quality are the chief source of supply. These average about 32 to 35 feet in depth. In wet weather they fill up with water. A deep well drilled for the Illinois Central Railroad had the following log:

Log of Illinois Central Railroad well at Rives, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay, dark, loamy	40	40
Sand, water bearing	20	60
Clay, blue "gumbo"	82	142
Sand coarse white, water bearing	18	160
Silty or bastard sand, very fine grained, with sticky blue clay in places (entered)	540	700

No water supply having been found below 160 feet, the pipe was pulled back and the well made at that depth. The water rises within 10 feet of the surface. The diameter of the well is 10 inches and 150,000 gallons a day are pumped for locomotive use.

In the hills west of Rives, which is on the broad second bottom or terrace, wells average 70 to 80 feet in depth. Cisterns are largely used.

At Samburg, at the foot of the lake bluff, water is obtained from numerous springs that flow from the bluff. Wells are very shallow and the water poor.

At Spout Spring there are some springs and ordinary wells, but cisterns are more commonly used than anything else.

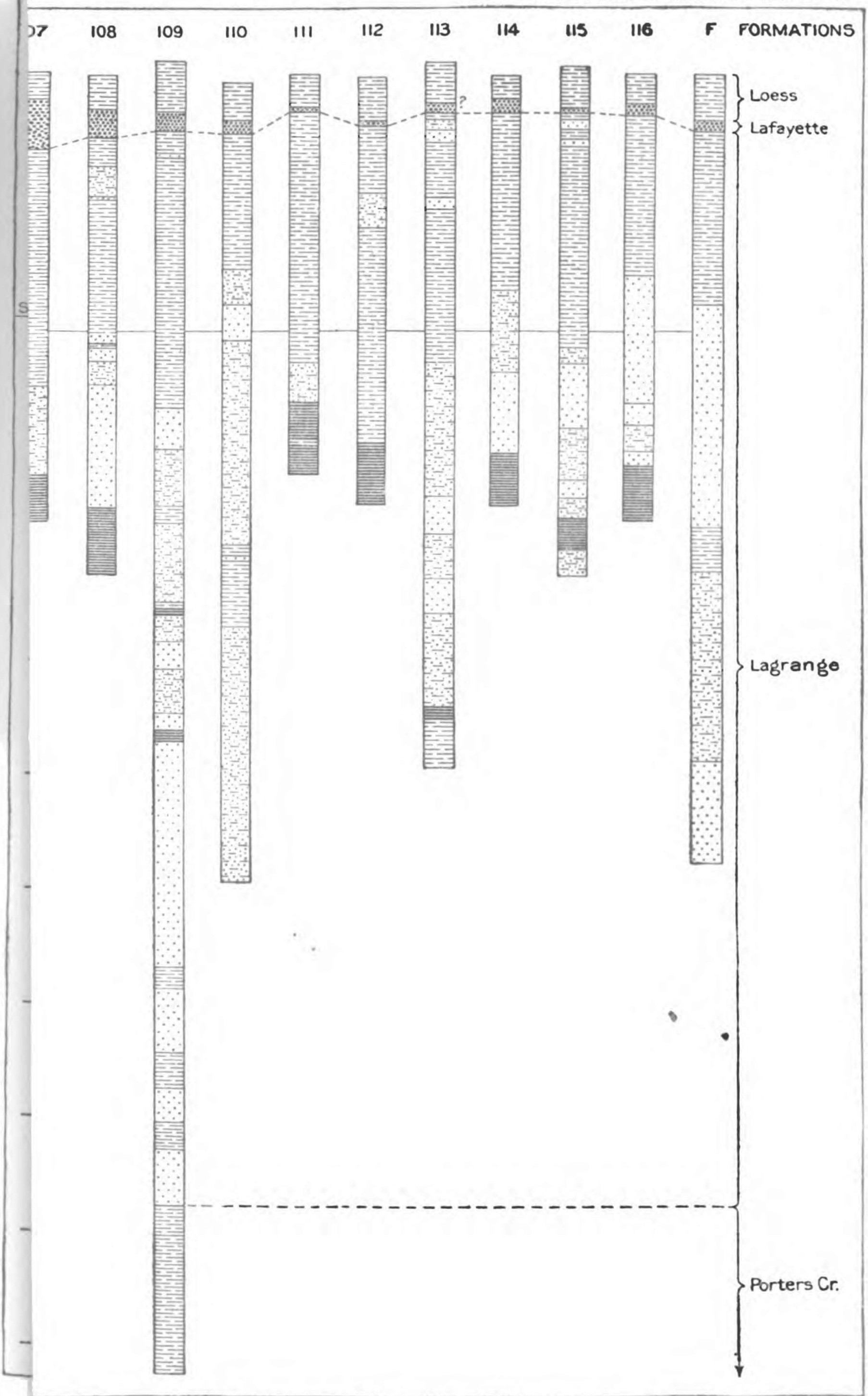
At Troy wells average about 25 feet in depth and furnish hard water.

At Union City, elevation 328 feet, water is obtained from open wells that average about 25 feet deep. Small tube wells are from 150 to 200 feet deep. The town waterworks has two 8-inch wells, each 150 feet deep, that pump 240,000 gallons per day. Each has 40-foot Cook strainers. The water rises within 35 feet of the surface. It is slightly hard, but does not form a scale. The ice company has an 8-inch well 125 feet deep, with a 30-foot Cook strainer. The water rises within 28 feet of the surface. It forms a little soft scale that is easily blown out of the boilers. The waterworks has since finished a 535-foot well, but no record could be obtained either of it or of the shallower wells. The health of the town is said to be greatly improved since deep water began to be used. Fevers, both malarial and typhoid, have decreased 50 per cent or more.

At Woodland Mills the domestic supply is obtained from dug wells of from 20 to 45 feet depth.

SHELBY COUNTY.

Topography.—Shelby County is in the southwest corner of Tennessee. It is bounded on the west by Mississippi River and on the south by the State line. The area is 769 square miles. The lowest portion of the county is the flat flood plain of the Mississippi and its tributaries, the largest of which are Loosahatchie and Wolf rivers. Along these latter streams there is usually a terrace or second bottom, but this is not so well developed nor so wide as the corresponding topographic feature in Obion County. The greater part of the county consists of the gently rolling upland that slopes slightly northwestward and ends abruptly on the western side in a line of bluffs that cross the county north and south and overlook the Mississippi swamp to the west. The average elevation of the county is about 300 feet. The highest point is about 400 feet above the sea and is on the southeastern edge of the county. The lowest point is where the Missis-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FORMATIONS
Loess
Lafayette
Lagrange
Porters Cr.

sippi leaves the State, low water there being about 200 feet above sea level.

Geology.—The Lagrange, Lafayette, loess, and alluvium are all represented in the county. The Lagrange is the underlying formation of the entire county. As shown in the deep well at Memphis (see p. 114), it is 950 feet thick, the upper 200 feet being clay and the remainder sand and clay interbedded in rapidly varying manner. Pl. VI shows the abrupt variation in the character of the individual strata of such deposits as the Lagrange.

The Lafayette overlies the Lagrange. In some places it has been entirely removed, but in others it reaches a maximum thickness of 30 to 40 feet. It consists of coarse sand with a large but varying proportion of gravel. Above it is the loess, which may attain a thickness of 60 to 80 feet, but is usually somewhat less. In the eastern part of the county it mingles with and passes into a surface loam which overlies the Lafayette. The river flood plains have a deposit of Recent alluvium that attains a thickness along the Mississippi of over 100 feet.

Water resources.—Springs and shallow wells in the loess furnish hard water. Wells in the alluvium also give poor water, which seems here, as elsewhere, to become more highly impregnated with iron, magnesia, and other mineral ingredients the deeper the well is sunk, so that, if shallow wells are to be used, the shallower the better, so far as the mineral contents of the water are concerned. In the loess area many use cisterns. Deep water of good quality may generally be obtained in the Lagrange at a depth of from 200 to 500 feet, though locally the sands are too fine for even the finest strainers, as has been the case in a number of borings in Memphis. A number of features concerning the Memphis supply that are discussed in the local data (p. 108) are more or less applicable to water-supply problems all over the county.

At Arlington cisterns are used and numerous shallow wells in gravel strike water at a depth of from 15 to 35 feet. Some of the water is soft, some hard, and some contains iron and sulphur. The Louisville and Nashville Railroad well, 228 feet deep, gets water in sand at 195 feet which rises within 12 feet of the surface. The water is pure and soft and excellent for locomotive use. The log, given from memory, is as follows:

Log of well of Louisville and Nashville Railroad at Arlington, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess	50	50
Orange sand and gravel	12	62
Clay, brown, with some lignite	133	195
Sand, white, water-bearing (entered)	33	228

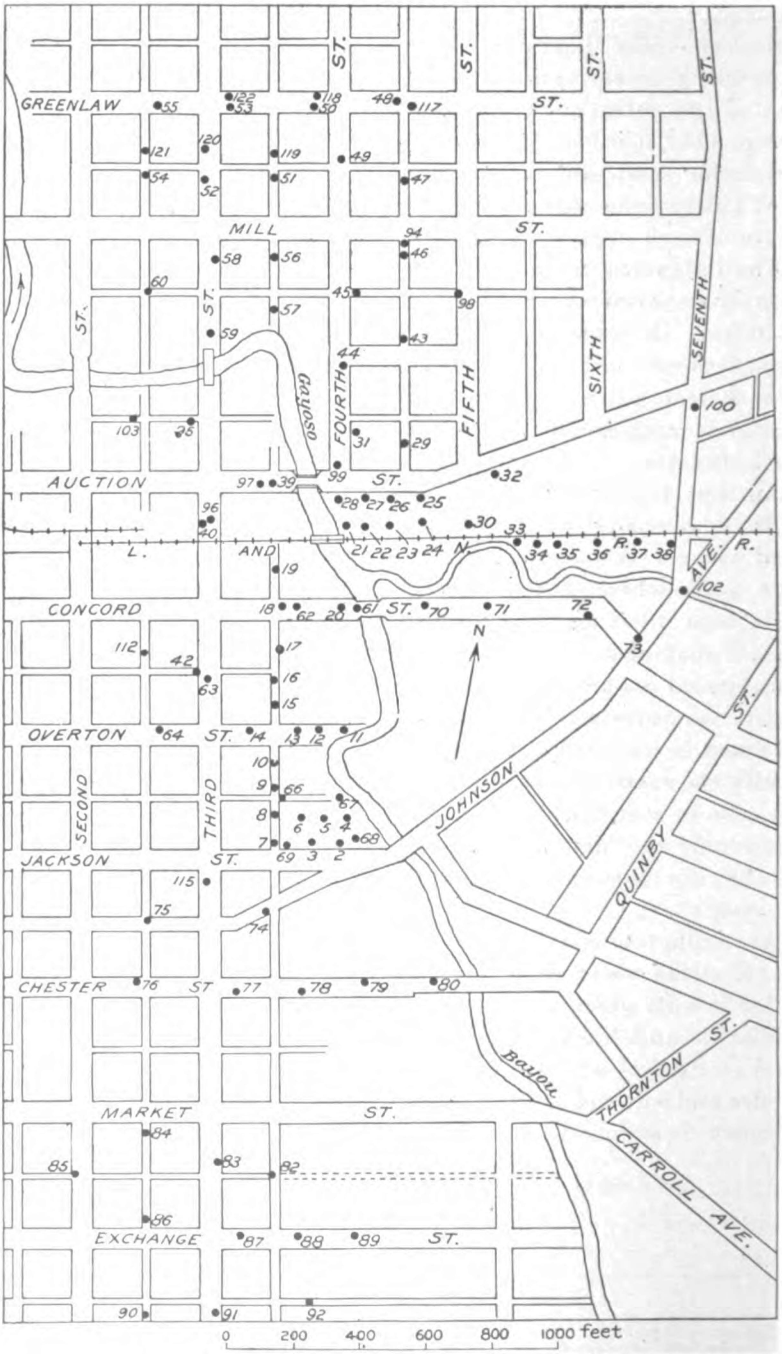

FIG. 8.—Diagram showing location of wells at Memphis, Tenn.

The strainer is 32 feet long and the well yields all that can be pumped by a suction pump set on the surface, of 24,000 gallons per hour capacity.

At Bartlett there are only common wells.

At Bleak there are ordinary shallow wells, some very strong springs, and a driven well 2½ inches in diameter and 176 feet deep, in which the water rises within 47 feet of the surface and is hard.

At Brunswick wells vary in depth from 20 feet in the lowlands to 70 feet on the hills. The lowland water is of poor quality. That in the hills is good and soft.

At Buntyn, elevation 290 feet, on the flat upland between Wolf River and Nonconnah Creek, water is found in the Lafayette or upper part of the Lagrange at depths that vary from 40 to 85 feet. Most wells are bored.

At Capleville, elevation 317 feet, cistern water is largely used. Wells range from 40 to 125 feet in depth. The deeper wells furnish soft water.

At Collierville, elevation 377 feet, cisterns were formerly used very largely. Water is found at a depth of 95 to 100 feet in sand so fine that it rapidly fills the wells and so but few are used. A town system of waterworks has been established with two wells 6 feet apart, driven 239 and 248 feet, with 16-foot Cook strainers. The water stands 95 feet below the surface and is raised by pumps that have a capacity of 7,500 gallons per hour. The water is reported to be very pure and fevers are said by physicians to have decreased 50 per cent since its use began. The log of the 248-foot well is as follows:

Log of well at Collierville, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay soil	6	6
Red sand and gravel	14	20
White sand with water at 95 feet; grows coarser downward	150	170
Pipe clay	8	178
Sand and gravel, water bearing	82	260

The gravel at 248 feet was better than that at 260 feet and the pipe was pulled back to it. Good pure springs are found at the foot of the ridge on either side of the town and wells in the lowlands of either the Wolf or the Coldwater average about 20 feet deep. There are several tubular wells 2½ inches in diameter and 130 to 140 feet deep in the vicinity. Most of them are pumped by gasoline or steam engines.

At Cordova, elevation 372 feet, water-bearing strata are struck at depths of 50, 80, and 100 feet. There are several small tubular wells that draw from the lowest stratum at a depth of 125 or 130 feet. The water is soft and is used for both boiler and domestic purposes.

At Eads, elevation 348 feet, there are very few wells or springs, cisterns being used almost exclusively.

At Foresthill open and bored wells are used, the latter being about 100 feet deep. The water is abundant and soft.

Germantown, elevation 377 feet, is supplied partly by cisterns and partly by wells that have a range in depth of 38 to 70 feet and an average of 60 feet.

Granberry obtains a supply chiefly from ordinary wells. One 2-inch well 118 feet deep furnishes an abundant supply of soft water for a gin and mill.

Irene gets its water supply from shallow wells and cisterns. One tubular well 2½ inches in diameter and 175 feet deep furnishes a boiler supply for a mill.

Kerrville, elevation 335 feet, gets its water supply almost entirely from ordinary dug wells 30 to 50 feet deep.

At Madge wells are from 20 to 75 feet in depth. The water is soft, but not always abundant.

At Massey, elevation 323 feet, there is one 200-foot well yielding water reported to be hard.

At Mayville, near Nonconnah Creek, there are only shallow bored wells.

Memphis has an elevation of 250 to 280 feet in the business part of the city, but in the eastern part the general elevation is 300 feet or more. Extreme low water in the Mississippi is 182 feet and extreme high water 218 feet. Prior to 1870 the entire water supply was obtained from cisterns and individual shallow wells. A public supply from Wolf River was then introduced, but it was never perfectly satisfactory, chiefly because of its turbidity. In 1886 an ice company sunk a well 354 feet deep and obtained a flow of water which rose several feet above the surface. Efforts to obtain a city supply from the same sources were so successful that a temporary pumping plant for the wells then sunk was erected in 1889 and the Wolf River plant abandoned. In 1890 the present pumping station was put into operation, and since then there has been a constant extension in the wells and the distributing mains. In August, 1903, 124 wells had been put down, of which 16 failed to find a stratum of coarse sand thick enough to justify completing them, and 4 had not then been connected. The first 42 wells sunk were abandoned in 1899, having had a life of about ten years each. The wells made now are of better material and are better cared for and will probably last fifteen years. For depreciation and city growth about eight or ten new wells are required each year. The cost of each new well is about $5,000.

The texture of the sand varies very rapidly, so that while the entire mass is water-logged, sand coarse enough to be kept out of a

strainer with slots one one hundred and fiftieth of an inch wide may not be found at the same level in two adjacent wells, but they may "get water"—that is, get coarse sand—at very different depths or one well may not get it at all (see fig. 9). If fine sand only is encountered, the well is not finished, as this sand cuts out the strainer slots in a year or two and also fills up the tunnels and pump well. At best the life of the strainers is only about three and one-half or four years. They are overhauled at the end of two years.

The yield per well varies considerably because of differences in the coarseness of the sand in which the strainers are placed. Wells 100 feet apart may show wide variation from this cause. Well No. 94 when new had a capacity of 988,000 gallons per month, while No. 98, one block distant, gave only 401,000 gallons per month. New wells should have a monthly capacity of 500,000 to 700,000 gallons. Within two or three months they usually run down to about 400,000. Occasionally one holds up for six months or a year. Five months after starting, well No. 94 had decreased to 591,000 and No. 98 to 363,000 gallons. This decreased flow is caused by the stopping up of the pores in the coarse sand around the strainer or of the slots in the strainer itself by fine sand carried in by the draft of water entering the well. To remedy it water is forced back by the pumps from the well into the sand around it. In this flushing a device is used that permits the water to be forced out through the slots of only a small portion of the strainer at a time, thus insuring a much more thorough cleansing than would otherwise be possible. Wells are flushed foot by foot about twice a year, and at times between they are flushed the entire length of the strainer at once. After flushing, the wells often show a larger flow than when new. Four wells that had fallen off 32 per cent in nine months increased their flow after flushing about 13 per cent above the original amount.

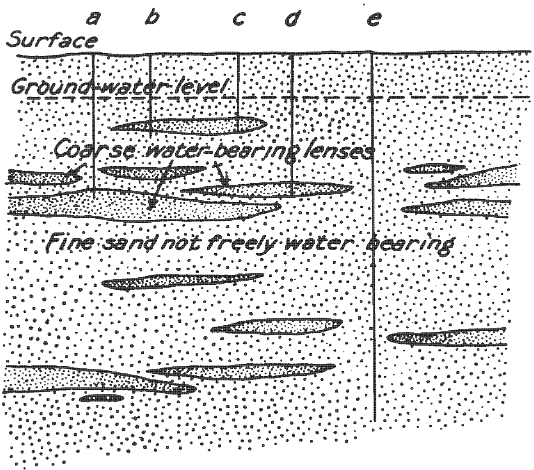

FIG. 9.—Diagram showing variation in texture of sand and its effect on depth and success of a well. Wells *b* and *c* obtain water from the same lens of coarse sand; wells *a* and *d* fail to strike this local lens, but go as deep again and obtain water at the same depth, but from different lenses; well *e* fails to strike coarse sand at all and is finally abandoned.

The level to which water from the Lagrange sand originally rose

at Memphis was 225.1 feet above the sea. This elevation was sufficient to permit it to flow at the surface in the lower parts of the city. Where the city wells have been put down the water will not rise to the surface. Instead of placing a pump in each well, the wells are connected by underground drifts with a reservoir, or tunnel, at

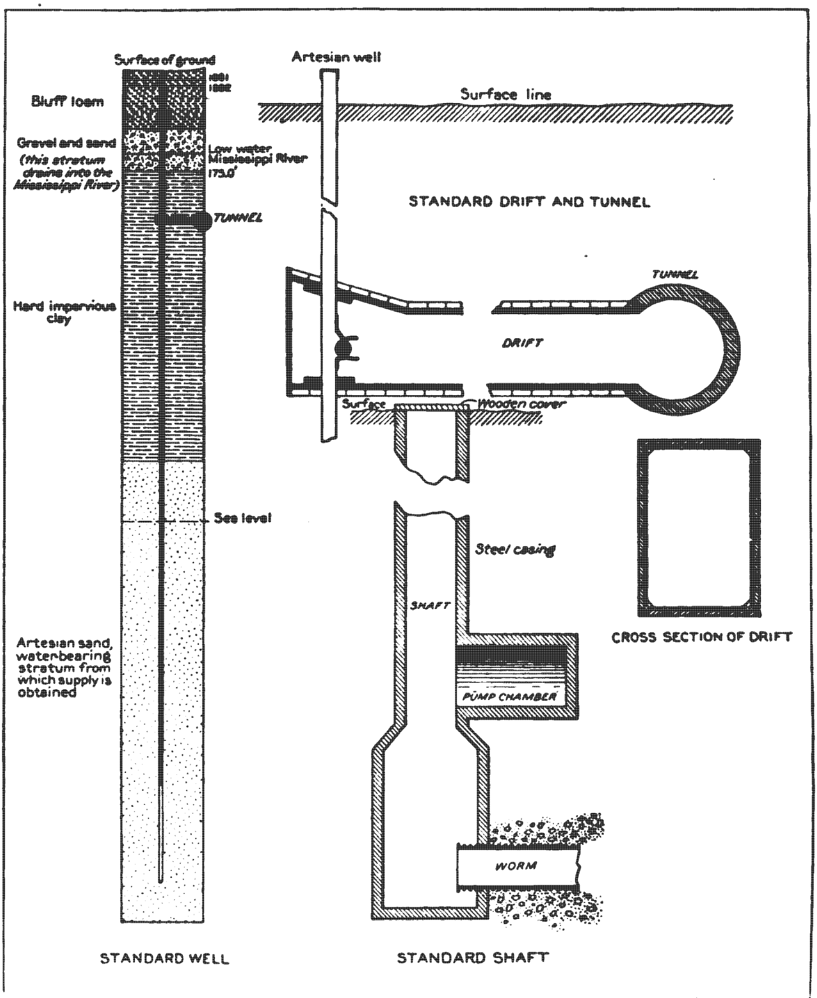

FIG. 10.—Section of well, drift, tunnel, and shaft at Memphis, Tenn. (After Hider, Omberg, and Bell.)

a level considerably lower than that to which the water would rise in them. The wells discharge into this tunnel, which is 5 feet in diameter and about three-fourths of a mile long. It is situated from 75 to 80 feet below the surface of the ground, in the upper part of the thick clay bed which underlies the city and forms the impervious upper member of the Lagrange formation at this point. In the

tunnel the water flows by gravity to a suction chamber, from which it is lifted to the surface by pumps and forced into mains for distribution over the city. At intervals shafts are sunk to the drifts, and in them are placed gates which permit groups of wells to be cut off from the remainder and each individual well to be shut off from the tunnel, so that it may be pumped out for inspection or repairs. A section of well, drift, tunnel, and shaft is shown in fig. 10.

When the water in the suction chamber is lowered to about the bottom of the suction pipes of the pumps, the wells flow under their greatest head. When less water is pumped, the level of the water in the pump well rises, the head of flow for the wells is lowered, and their flow automatically diminishes until it equals the amount being pumped. The plant contains three Worthington direct-acting pumping engines, each of 10,000,000 gallons daily capacity. The water is forced by these pumps directly into the mains, which connect with a steel standpipe 20 feet in diameter and 160 feet high. This serves chiefly as a pressure regulator, though to a very limited extent it also acts as a reservoir.

The water is clear and sparkling when freshly drawn, but on exposure or heating gives off free carbonic acid gas and then precipitates iron oxide, the iron at first existing in the water as a carbonate. The nascent carbonic acid attacks the threads on wrought-iron pipe and corrodes them, but does not seriously damage brass or cast iron or the inside of wrought-iron pipes. In steam boilers a scum or soft scale is formed, but does little or no damage if the boilers are frequently cleaned. For drinking and many other purposes the water is very satisfactory, but there is enough calcium carbonate present to interfere somewhat with its use in laundry work, for which many use cistern water. When the artesian water is heated, however, it precipitates the calcium carbonate and may then be used for washing.

Analyses of Memphis artesian water.

	1.	2.	3.	4.	5.
Volatile solids	24.94	14.96	19.96	....	....
Fixed solids	64.86	69.86	74.84	....	....
Total solids	89.80	84.82	94.80	86.64	92.85
Chlorine	2.165	2.095	2.494	1.796	None.
Silica	Little.	Little.	....	Little.	Present.
Nitrates	None.	None.	None.	None.	....
Nitrites	.032	.023	.023	Faint trace	....
Free ammonia	.012	.000	.006	.014	.009
Albuminoid ammonia	.009	.006	.006	.031	.014
Oxygen consumed	.000	.000	.000	.420	....

1, 2. Charles Smart, analyst, June, 1887.
3. Charles Smart, analyst, July, 1888.
4. J. W. Mallet, analyst, June, 1887.
5. E. H. S. Bailey, analyst, June, 1887.
In addition Professor Mallet reports as present soda, potassia, lime, magnesia, iron, iron carbonate, sulphates, traces of phosphates, free nitrogen, almost no oxygen, organic carbon 0.86, organic nitrogen 0.28 part per million.

There has been a remarkable lowering of the death rate since the introduction of the artesian water and the extension of the sewerage system. While this has been partly due to better sanitary conditions resulting from the development of the sewer system, it has also been due largely to the healthfulness of the water itself. The increase of population, extension of sewers, and increased use of city water are graphically shown in their relationship to the decreasing death rate in fig. 11.

Most of the wells in use are located within an area of a quarter of a square mile, and it is calculated that the ultimate limit of economic supply from this area will be about 25,000,000 gallons per day. The present daily consumption is over 20,000,000 gallons and this rate shows each year an increase of about 1,000,000 gallons. In order not to interfere with the yield of the present cluster of

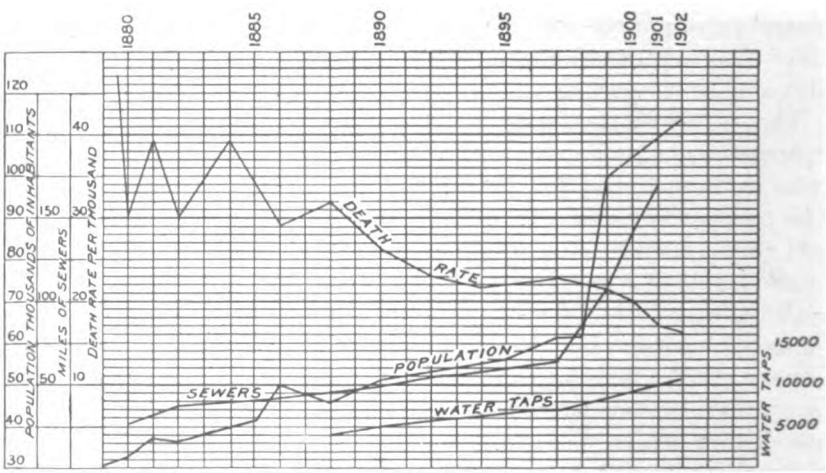

FIG. 11.—Diagram showing increase of population and decrease of death rate in Memphis, Tenn., after the extension of sewers and water mains. (After Hider, Omberg, and Bell.)

wells, new wells are now being located in South Memphis, at a distance of 4 or 5 miles from the old wells, where a new group may soon be developed, so as to give a similar yield of about 25,000,000 gallons a day from a quarter of a square mile. When the city has grown large enough to require a daily supply of 50,000,000 gallons additional units must be provided to meet both the normal increase in consumption and the deterioration in condition and consequently decreased yield of the units already fully developed. It is conceived by the writer that just as the sand in the small area around each well becomes more or less clogged by the indraft of water to the well, so the sand around any quarter square mile or other unit area will in time become similarly clogged and show a decreased yield. Such decrease will be permanent, for it will manifestly be

impracticable to flush out an underground area of even comparatively small size when in order to flush a single well most efficiently it must be taken a foot at a time. The expansion of the present system involves an extension of mains and the erection of new substations at considerable cost. The writer believes that the present system is not capable of indefinite expansion, and hence that it can not be regarded as a permanent system for a rapidly growing city like Memphis. When it has been extended to its ultimate economic limit, the city must either turn to Mississippi River for a water supply or explore the deeper lying sands in the hope that they may yield a more abundant supply than is found in the Lagrange. When this limit will be reached it is impossible to say. It may be reached in twenty-five years from now, or it may possibly be fifty years. The present supply has numerous advantages from a sanitary point of view which render its retention and further enlargement advisable as long as it can be done with economy.

The problems arising from the use of Mississippi River water do not require extended discussion here. If the turbidity were removed by settling or filtration, or a combination of the two, the principal objection to the use of the river water would be removed. Other problems would be of purely an engineering character and would be as capable of easy solution.

The hydraulic level in the vicinity of the city pumping plant has been successively lowered by the increase of the amount pumped so that the actual hydraulic surface in the water-bearing sand around the city pumping station forms an inverted cone whose apex is a point in the pump shaft at an average elevation above the sea of 170 feet, the water in the shaft being kept down to this level by the pumps. The curves made by the hydraulic surface in 1898 and in 1902, when about 9,000,000 and 12,000,000 gallons, respectively, were pumped daily, are graphically shown in fig. 12. The probable surface resulting from the establishment of a second pumping plant is also shown.

In view of the steady increase in the consumption of water, the Ripley formation should be tested as a water bearer. It would not take much additional work to deepen the 1,147-foot well sufficiently for that purpose, since it can not be far above the top of the Ripley as it now stands. Details as to the probable thickness of the Porters Creek formation at Memphis are given on page 31. It is impossible to predict accurately the condition of the Ripley beds at Memphis or the character of the water they may contain. It is very probable that this formation would be found there, as elsewhere, to be coarse enough to be a water bearer and that the water contained in it would be of good quality. There is no special reason, indeed, for believing that it would yield water much different from that now

obtained in the Lagrange sands, for the two formations are very similar in lithologic character. Should the deep well be sunk to the Ripley and the water there be found insufficient in quantity or inferior in quality the well need in no wise affect the present supply. If it were desired to shut off the water, the well could be plugged at any depth desired and the pipe above that depth either cut or allowed to remain.

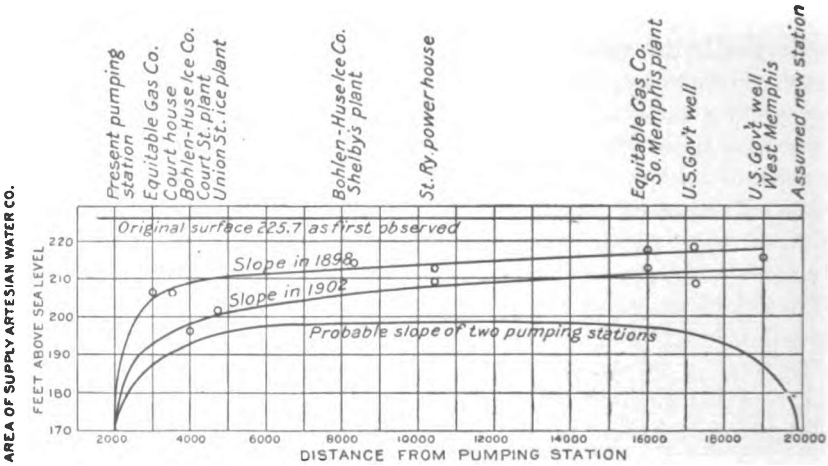

FIG. 12.—Diagram showing slope of artesian hydraulic surface and probable effect of a second pumping station at Memphis, Tenn. (After Hider, Omberg, and Bell.)

The Ripley is probably underlain by the Selma clay, and it in turn by the Eutaw sand, which is also water bearing. The depth, however, to the Eutaw at Memphis is probably so great as to prevent its economical use for city water supply unless the yield per well were much greater than that obtained from any of the wells now in use.

Log of Well No. 109, Memphis, Tenn.

[Elevation, 238 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	27	27
Hard brown clay	10	37
Slightly soft brown clay	8.4	45.4
Gravel and sand	4	49.4
Soft brown clay and sand	14	63.4
Slightly hard brown clay	12.5	75.9
Stiff blue clay	3	78.9
Soft blue clay	4.4	83.3
Stiff blue clay and sand	2.6	85.9
Soft brown clay and sand	1	86.9
Very hard brown clay	2	88.9
Hard reddish clay	1.5	90.4
Hard blue clay	15.5	105.9
Soft blue clay	15.1	121
Stiff blue clay	1	122
Soft brown clay	4	126
Slightly hard brown clay	1.3	127.3
Stiff brown clay	1	128.3

Log of Well No. 109, Memphis, Tenn.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Hard brown clay	1	129.3
Very hard brown clay	5.7	135
Hard brown clay	61	196
Slightly hard blue clay	18	214
Hard blue clay	9	223
Sandy blue clay	53	276
Fine sand and clay	27	303
Fine sand	35.4	338.4
Fine sand and lumps of blue clay	41.6	380
Coarse sand and lumps of blue clay	10	390
Soft blue clay	17	407
Sandy blue clay	10	417
Fine sand and clay	15	432
Sandy blue clay	13	445
Fine sand and clay	7	452
Sandy blue clay	22	474
Fine sand	26	476.6
Sandy blue clay	6.6	483.2
Fine sand	.8	484
Coarse sand and clay	6	490
Soft blue clay	2.3	492.3
Clay and sand	17.7	510
Very fine sand	25	535
Very fine sand and clay	38.2	573.2
Very fine sand	16.8	590
Very coarse sand with lignite	8	598
Lignite, pyrite, and clay	2	600
Very fine sand and lignite	195	795
Soft white clay	17	812
Very fine sand	53	865
Hard brown clay	31	896
Fine white sand	30	926
Hard brown clay	24	950
Fine sand	50	1,000
Stiff brown clay	25.6	1,025.6
Very hard, substantial rock	.5	1,026.1
Very stiff blue clay	27.9	1,054
Very hard clay	93.5	1,147.5

At Millington water is obtained at a depth of 20 to 40 feet and better water at 80 to 100 feet. Cisterns are largely used.

At Mulkins, elevation 284 feet, water is obtained from springs, cisterns, and wells that average 30 or 40 feet in depth.

At Pearley the wells are from 16 to 60 feet deep.

At Ramsey cisterns only are used.

At Sloanville water is struck in Lafayette gravel at a depth of 34 feet. Water-bearing gravel is also reached at a depth of 83 feet. Some wells yield soft water, but in most it is hard.

At Whitehaven, elevation 303 feet, only dug or bored wells of about 50 feet average depth are in use.

TIPTON COUNTY.

Topography.—Tipton County is bounded by Mississippi River on the west. Its area is 430 square miles. The surface may be divided topographically into three parts, the lowest of which is the alluvial plain of Mississippi and Hatchee rivers. This low plain forms a narrow belt along the western and northern borders. Next, there is along the Hatchee a terrace belt of varying but not great width. The third part is the upland surface, which is gently rolling or level

except near the bluffs that form its western margin, where it is cut into steep-sided hills. The average elevation is about 325 feet, but the elevations of only a few points in the county are known. The highest of these is 378 feet, on top of the bluff at Randolph. The lowest (about 200 feet) is at low water in the Mississippi where it leaves the county.

Geology.—The geology of the county is exactly similar to that of Shelby County, just south of it. The Lagrange everywhere underlies the alluvium in the bottoms, and the Lafayette on the uplands. The Lafayette in turn is overlain by the loess and the latter seems to extend down onto the terrace area.

Water resources.—The county is fairly well watered by flowing streams, which are the main dependence for stock water. For domestic use, wells, cisterns, and springs are used, wells being the most common. Wells in the loess, as well as springs that flow from it, give hard water. The use of small driven wells from 100 to several hundred feet deep is becoming more general. Good soft water from the Lagrange sand should be obtained almost anywhere at depths of from 100 to 250 feet. The entire drainage is to the Mississippi.

At Almira wells average 65 or 70 feet in depth; some are dug, others bored. The dug wells are the more satisfactory. The water is generally soft.

At Atoka, elevation 424 feet, water is obtained chiefly from ordinary wells. There are a few springs, but most of them go dry during the summer.

At Bride there is difficulty in drilling wells because of caving. The water is hard. Cisterns are used almost exclusively.

At Covington, elevation 316 feet, water is generally obtained from open wells of about 40 feet average depth. The town system is supplied by four wells 6 inches in diameter and 100 to 110 feet deep. Each flows 3 gallons a minute under a head of about 5 feet. The daily consumption is 50,000 gallons. Direct pressure is used. The water is soft and of excellent quality, and the health of the town has been greatly improved by its use. The section, reported from memory, is as follows:

Log of wells at Covington, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay	8	8
Blue clay	4	12
White and reddish sand	12	24
Coarse white sand	86	110

At the station the Illinois Central Railroad has an 8-inch well 533 feet deep, in which the water rises within 31 feet of the surface. It

has a temperature of 66° F., is soft, and makes a good boiler water. Nine thousand gallons per minute may be obtained with the present pumping plant. The record given is as follows:

Log of well at Illinois Central station, Covington, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Blue clay	100	100
Fine white sand	18	118
Blue clay	100	218
Quicksand	100	318
Fine tough gray clay	182	500
Sand	4	504
White pipeclay	4	508
Very coarse sand, water-bearing	25	533

At Dawsons the wells on the upland range from 40 to 80 feet in depth. An occasional well furnishes soft water. Wells in the bottoms are 10 to 20 feet deep, and the water rises to the top during the winter.

At Gift cisterns are used.

At Mason water is obtained at a depth of about 35 feet. One well is 200 feet deep.

At Phelan water is obtained from dug wells 45 to 60 feet deep. The water in most of them is good, but is easily lowered.

At Quito cisterns are most used. Wells average 35 feet in depth, and the water is generally hard. Two miles to the west, along the bluffs overlooking the Mississippi alluvial region, springs are abundant.

At Tabernacle there is a 4-inch bored well sunk to a depth of 225 feet. The water is abundant and soft and rises to within 106 feet of the surface. The section down to 184 feet, where the water rose 78 feet in the pipe, was chiefly alternating sand and clay. This was followed by a thin sand-ironstone layer, then 21 feet of blue clay, and beneath it another sand, which was entered to a depth of 225 feet from the surface. The water in this sand rose within 165 feet of the surface only, and so the casing was pulled back and the well made at 184 feet.

At Tipton, elevation 342 feet, dug wells from 30 to 50 feet in depth furnish hard water. Some springs are also used.

At Walts, on the Mississippi, the only wells are shallow driven wells in which the water rises and falls with the river surface. The quality of the water is not good; the shallower the wells are the less iron the water contains.

WEAKLEY COUNTY.

Topography.—Weakley County is bounded by the Kentucky line on the north and is almost midway between Tennessee and Mississippi rivers. Its area is 565 square miles. The surface is gently rolling,

except around Dresden and in the northeastern part of the county, where it is hilly. The general slope is westward and the drainage is to the Mississippi. Elevations of about 500 feet are found on some of the hills near Dresden. South Fork of Obion River has an elevation of about 290 feet where it leaves the county, and North Fork is but slightly higher. The average elevation is between 400 and 450 feet.

Geology.—The formations of the county are the Lagrange, the Lafayette, and the Columbia loam. The Lagrange underlies the entire county, and while generally concealed by one or both of the other formations it is exposed in the deeper railway and stream cuttings. It consists, as usual, of soft sands interbedded with occasional strata of clay. The Lafayette is a red clayey sand and contains very little gravel. It is 10 to 20 feet thick and is exposed in most of the natural and artificial cuttings. Over it are generally found 5 to 10 feet of a softer, lighter-colored sandy loam that in places is very much like loess in its physical characteristics.

Water resources.—The county is watered by numerous streams, the larger of which flow westward. Many of the smaller streams become dry during the late summer and autumn and recourse is then had to ponds and wells for stock water. Springs are not numerous nor strong. The ground-water level, as is often the case in the middle and eastern parts of the Lagrange belt, lies at some distance below the surface, and wells which furnish the chief water supply average 50 or more feet in depth. In some cases, where the depth to water is greater than usual, cisterns are used.

At Dresden, elevation 416 feet, there is no system oi waterworks; water is obtained chiefly from open wells that average 50 feet in depth. The water is good, soft, and abundant. A few persons use cisterns. In the surrounding country wells in low places near streams may be only 20 feet deep, while on hills they go to 80 feet or more.

At Gardner, elevation 337 feet, water is obtained from common open wells only.

At Gleeson Station, elevation 397 feet, good water is struck at depths of 50 to 100 feet.

At Greenfield, elevation 434 feet, ordinary wells are in general use. There is one well 200 feet deep and another 400 feet deep, detailed records of which could not be obtained. The water in the 200-foot well rises within 116 feet of the surface, and is pumped; the yield is 60 gallons per minute. The water contains some iron and is used for domestic and boiler purposes. The water in the 400-foot well rises to about the same elevation, but is dark colored and does not taste good.

At Kimery springs are weak and of little use. Wells 25 to 100 feet deep and small tubular wells 100 to 160 feet deep are used The water is soft, and, in the deeper wells, abundant.

At Logan water is obtained from springs along the hillsides and from wells that average 50 feet in depth.

At Martin, elevation 419 feet, water is obtained from cisterns and open wells. The wells range from 60 to 90 feet in depth and furnish good soft water from the Lagrange sand. Occasionally a well strikes water above a local hardpan, at the base of the Lafayette, at a depth of 20 or 25 feet. If this hardpan is dug through the water immediately drains down into the underlying dry Lagrange sand, and permanent water is not reached short of 60 to 80 feet below the surface.

The town put in a system of waterworks in 1898, getting the supply from two 8-inch wells, each 316 feet deep. The water rises within 90 feet of the surface, and is raised by air lifts, with a capacity of 12,000 gallons per hour for each well, into two surface reservoirs of 28,000 and 96,000 gallons capacity. From these it is forced into the mains by direct pressure. The town wells are on a level with the railway crossing. No complete log could be obtained. The water is so clear that it looks bluish; it is soft and excellent for domestic and industrial purposes. The ice company has a 4-inch well 130 feet deep, the top of which is about 2 feet lower than the town wells. The water rises within 69 feet of the surface, and is of good quality. From the record of this well and other sources the following may be given as the approximate section at Martin:

Generalized section at Martin, Tenn.

	Feet.
Surface sand and clay	20
Sand with occasional beds of clay, each 3 or 4 feet thick	50
Sand, water bearing	10– 15
Pipe clay (to a total depth of 100 feet)	15– 20
Sand, water bearing	30±
Clay, black lignite	60– 90
Sand, fine, with clay	80–100
Sand, coarse, water bearing	15+

The upper water-bearing sand seems to run very uniform in elevation in the vicinity of Martin, ranging in depth from 25 feet in the valleys to 150 or 160 feet beneath the hills. The layer of lignitic clay is also reported to underlie a large part of the country around Martin. Some parts are pure enough lignite to burn when dried. Occasionally a log of lignite is struck in the sand over the lignitic clay.

At Meda, elevation 424 feet, water is obtained from cisterns, from shallow dug wells 25 to 40 feet deep, and from small bored wells 50 to 100 feet deep. The water is soft, but is not very abundant.

At Ore Spring there are some ordinary springs and shallow open and deep bored wells, the latter ranging from 60 to 100 feet in depth. The water is abundant and soft.

At Ralstons Station, elevation 429 feet, water is obtained from cisterns, and shallow wells 25 to 40 feet deep. There is one tubular

well 166 feet deep that furnishes an abundance of soft water, but no record of it could be obtained.

At Rinda water is obtained from bored wells 30 to 150 feet deep.

At Ruthville water is obtained from cisterns and from ordinary wells 50 to 75 feet deep.

At Sharon, elevation 416 feet, water is obtained from wells, cisterns, and ponds. The wells range in depth from 50 to 150 feet, but the water is especially good and abundant at 100 to 150 feet. At the foot of the hills on the north side of Obion River are numerous springs. Small streams go dry in the fall and ponds are used for stock water.

At Terrell there are wells from 30 to 60 feet deep.

At Unity water is obtained from common wells and springs.

MINERAL WATERS OF WESTERN TENNESSEE.

There are a number of mineral springs or wells in western Tennessee that are more or less widely known for their therapeutic properties. Some few have been developed into summer resorts, but most are undeveloped and are used only locally.

Austin Springs, at Unity, Weakley County, have something more than a local reputation for their medicinal properties. They are 15 miles east of Fulton, Ky. The water is a sulphureted chalybeate, in which iron is the chief ingredient, but small amounts of calcium, magnesium, potassium, sodium, and chlorine are also reported present. It is reputed to be valuable for rheumatism and general kidney and stomach troubles. The water is sold locally.

At Bethel Springs, McNairy County, elevation 458 feet, there is a chalybeate spring that has long been known and used for its curative properties. No analysis is known to have been made.

Brock Springs, in the western part of Weakley County, 10 miles west of Dresden, is a local resort, but has no permanent improvements. Visitors camp out and live in tents. The quality of the water could not be ascertained.

The Cotton artesian well, half a mile southwest of Huntington, Carroll County, was bored in 1879 to a depth of 67 feet and cased with terra-cotta piping. The water flows several gallons per minute. It is a very palatable chalybeate. A hotel has been erected near it.

Dunlap Chalybeate Springs are about 2½ miles south of Bolivar, Hardeman County.

At Dyersburg the water for the Phoenix Cotton Oil Company's deep well has considerable local repute for use in kidney troubles. No analysis has been made, but it is known to contain considerable iron and a little calcium, and probably magnesia also.

The water from Essery Springs, 3 miles south of Pocahontas, on

the southern edge of Hardeman County, has been known for years and used for kidney and stomach disorders.

Gibson Wells, 12 miles northwest of Humboldt, Gibson County, is one of the best developed summer resorts of western Tennessee. Extensive hotel accommodations have been provided. The wells afford chalybeate and sulphur waters that are used for indigestion and nervous and malarial disorders.

Glenn Spring, 7 miles from Atoka, Tipton County, is at the base of the Mississippi River bluffs. The water has long been used for liver, kidney, and digestive disorders. The following analysis was made in 1880 by W. T. Lupton:[a]

Analysis of alkaline carbonate water from Glenn Spring, Tennessee.

	Parts per million.		Parts per million.
Silica (SiO_2)	24	Carbonate radicle (CO_3)	206
Iron (Fe)	4.5	Sulphate radicle (SO_4)	2.6
Calcium (Ca)	66	Chlorine (Cl)	1.7
Magnesium (Mg)	35		
Sodium (Na)	13		355.4
Potassium (K)	2.6		

The water from Hargrove Spring, 6 miles south of Ripley, Lauderdale County, is alkaline and useful, especially in kidney and bladder troubles and for gout and rheumatism.

Hawkins Spring, 1½ miles from Huntington, Carroll County, on the edge of the bottoms, is a bold chalybeate spring.

Hinson Springs is on the Nashville, Chattanooga and St. Louis Railway, 2 miles west of Lexington, Henderson County. There are two chalybeate springs, two sulphur springs, and a freestone spring, all near each other. The place has been a summer resort for fifty or seventy-five years. The waters have not been analyzed, but they are recommended for stomach, kidney, and bladder troubles.

At Jackson there is an artesian well, which forms part of the city water-supply system, and yields water that is regarded as having medicinal properties. A description of it has already been given (p. 97). The water is slightly chalybeate and alkaline, as the following analyses show:

[a] Crook, J. K., Mineral Waters of the United States, p. 439.

Analyses of water from well at Jackson, Tenn.

[Parts per million.]

	1.	2.	3.	4.
Silica (SiO_2)	16	14	15	1.2
Oxides of iron and alumina ($Fe_2O_3+Al_2O_3$)	45		.50	6.4
Calcium (Ca)	1.6		2.9	4.3
Magnesium (Mg)	.67	4.2		2.9
Sodium (Na)	12	5.1		12
Carbonate radicle (CO_3)	19	([a])	2.5	21
Sulphate radicle (SO_4)		26	3	
Chlorine (Cl)	1.3	1.7		5.1
Potassium (K)		1.4		
Free ammonia		None.		
Albumin oil ammonia		Trace.		
Residue on evaporation			55.7	
Residue on ignition			44.7	
Soluble organic matter			23.9	
Insoluble organic matter			20.8	
Nitrate radicle				7.6

[a] Not determined.

1. C. N. Miller, analyst.
2. W. E. Stone, analyst. "The water is to be regarded as exceptionally pure. The solid matter is present in quantities so small that it is difficult to make the determination; its form is mainly that of sulphate of soda and lime, with traces of potash and magnesia."
3. Henry Carmichael, analyst. "The water represented by above sample is exceptionally soft and is well adapted for boiler supply or bleaching purposes."
4. Pittsburg Testing Laboratory, analyst.

Mason's wells, in Madison County, 3 miles from Pinson and 11 miles from Jackson, have long had a reputation for their curative properties in stomach and kidney disorders. The water is chalybeate and mildly astringent. The principal well is 70 feet deep and has 30 feet of water in it.

Pryor Chalybeate Spring, 2½ miles east of Paris, Henry County, has a bold flow.

At Raleigh, Shelby County, is a group of six springs that were analyzed by Mr. Theo. Hernner and found to contain the following:[a]

Analysis of water from springs at Raleigh, Tenn.

	Parts per million.		Parts per million.
Silica (SiO_2)	26	Carbonate radicle (CO_3)	86
Iron (Fe)	31	Sulphate radicle (SO_4)	10.3
Calcium (Ca)	23	Chlorine (Cl)	6.2
Magnesium (Mg)	9		
Sodium (Na)	6.3		197.8

Sulphur Springs water, Decatur County, has a local reputation for dyspepsia and stomach troubles. No analysis has ever been made.

RESOURCES OF KENTUCKY, BY COUNTIES.

BALLARD COUNTY.

Topography.—Ballard County is in the extreme northwestern part both of the Jackson purchase region and of the portion of Kentucky

[a] Safford, J. M., An annotated catalogue of the mineral springs and wells of Tennessee, a contribution to a report on the water supply of the State: Suppl. to Bull. State Bd. Health, Tenn. for Oct., 1885, pp. 15, 16.

lying west of the Tennessee River. It is bounded on the west and north by Mississippi and Ohio rivers and on the south by Mayfield Creek. Its area is 237 square miles. The county is divisible topographically into three parts that differ in their general surface elevation as well as in other respects. The lowest of these is the flood plain or bottoms along Mississippi and Ohio rivers. This is absent at Wickliffe, where the Mississippi is swinging eastward against the bluffs, but its width reaches 6 miles in the middle western part of the county and decreases to a mile at the northeast corner of the county. The surface of this plain is broken by a number of low sand ridges whose general trend parallels the river. These ridges are separated by old lakes, ponds, and sloughs—the remains of abandoned and partly filled river channels. The average elevation of this part of the county is between 300 and 320 feet. The higher ridges and the margin along the river bank are cultivated in many places, but the greater part is a poorly drained wooded swamp. The second topographic division is an old terrace level with a surface about 30 or 35 feet higher than that of the flood plain. This forms a belt 4 to 6 miles wide that crosses the northern part of the county adjacent to the flood-plain belt. The remaining and largest part of the county is the general upland region, which has an elevation of between 400 and 425 feet. The surface is level or gently rolling except near the western margin and along the streams, especially Mayfield Creek, where it is hilly.

Geology.—The surface formations are the Lagrange, Lafayette, loess, and alluvium. The Lagrange underlies all of the county except the northern part, where both the Porters Creek and the Ripley are doubtless to be found beneath the thin covering of alluvial material. They are not exposed naturally and no wells have been sunk to them in the alluvial region; their exact position and boundaries are therefore largely conjectural. The Lagrange has its usual character, being a soft, light-colored sand with occasional strata of clay. It is exposed only in the sides of the deeper and more abrupt cuttings.

Over the Lagrange is a layer of 10 to 30 feet of Lafayette sand and gravel. This extends over the entire upland area of the county, except where it has been removed by stream erosion. It apparently covers the terrace area in the northern part of the county also, though the writer is not sure that this gravel is as old as the Lafayette gravel on the uplands to the south. It seems more probable that it is an Ohio River gravel of later age. This terrace belt extends up the Ohio to Paducah, McCracken County, which is situated on it, and beyond, and throughout presents the same characteristics and the same problem as to the age of its gravels.

The alluvium covers the flood plains of the two great rivers.

Water resources.—There are numerous streams that generally fur-

nish water for stock. In some places, where the surface is flat, natural ponds hold water practically all the year, and artificial ponds may be readily made. The alluvium furnishes water everywhere at slight depths, but the quality of such water is generally poor to fair only. The gravel on the terrace and on the upland is often water-bearing. In the terrace gravels the water is usually hard, while on the uplands the water from the Lafayette is in some places hard and in others soft. In numerous places, however, there is no hardpan or clay at the base of the Lafayette to form an impervious basin, and then water is only reached at a considerably greater depth in the Lagrange. An abundance of water of good quality should be found practically everywhere at the base of the embayment deposits or in the immediately underlying chert that forms the upper part of the Paleozoic floor. The depth to this old floor is probably not over 400 or 500 feet, except on the southern edge of the county, where it seems to sink rapidly to 1,000 feet. Good water may be obtained in sufficient quantity for manufacturing or domestic purposes from the Lagrange sand, at depths of 150 to 300 feet, in almost any part of the county. Over the uplands ordinary wells are 60 to 100 feet deep.

At Bandana, on the terrace plains, water is obtained by ordinary wells at moderate depth.

At Barlow City water is struck at a depth of about 70 feet. Bored wells and cisterns are used.

At Blandville, elevation 445 feet, cisterns are used principally, but there are some open wells that reach 140 feet in depth.

At La Center, elevation 404 feet, there is a deep well drilled for the Illinois Central Railroad for engine use, the log of which is as follows:

Log of Illinois Central Railroad well at La Center, Ky.

		Thickness.	Depth.
		Feet.	*Feet.*
Clay (loess, loam)		20	20
Sand and clay	(Lafayette)	18	38
Cement gravel	(Lafayette)	38	76
Sandy clay	(Lagrange)	34	110
Marl and streaks of sand	(Lagrange)	28	138
Gumbo (Porters Creek)		112	250
White sand	(Ripley)	5	255
Brown sand and clay	(Ripley)	132	387
Limestone	(Mississippian)	10	397
Gumbo and "Elco" gravel, mixed	(Mississippian)	48	445
Brown sand and clay	(Mississippian)	113	558

At Lovelaceville, in a valley tributary to Mayfield Creek, the wells are from 30 to 40 feet deep. The water is hard in some and soft in others. In the neighboring hills wells run 50 to 100 feet in depth.

At Ogden there are few cisterns; most of the supply is obtained from bored wells. The region is so flat that there are no springs.

At Oscar there are only shallow wells.

At Slater there are some wells ranging from 40 to 75 feet in depth, but the water is generally considered poor and is very little used. Cisterns are almost exclusively used for domestic supply, while ponds are used for stock.

At Wickliffe, elevation 322 feet, there are only a few open wells that average 40 or 50 feet in depth. In the surrounding country the farmers use cisterns almost exclusively, the water from shallow wells being hard because of the loess.

The town built waterworks in 1901, getting the water from a 6-inch well 147 feet deep, from which 6,000 gallons per hour are pumped into a standpipe for distribution. The log is as follows:

Log of waterworks well at Wickliffe, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	6	6
Dark clay	30	36
Sand, with a little water	2	38
Blue clay, partly sandy	90	128
Coarse sand, water bearing	19	147
Potters' clay (penetrated)	5	152

The casing was pulled back to 147 feet and the well finished with a 19-foot strainer. The yield has shown no tendency to decrease. The water is soft and quite satisfactory for general town purposes and for boiler use.

Analysis of water from waterworks well at Wickliffe, Ky.

	Parts per million.
Silica (SiO_2)	21
Oxides of iron and aluminum ($Fe_2O_3 + Al_2O_3$)	8.6
Calcium (Ca)	9.5
Magnesium (Mg)	5.1
Sodium (Na)	6.7
Carbonate radicle (CO_3)	27
Sulphate radicle (SO_4)	5.8
Chlorine (Cl)	6
Free CO_2	85
Alkalinity	70
Incrusting solids	71
Nonincrusting solids	19

A few years ago a local company drilled for oil in the southern edge of town and got artesian water instead. The elevation of the well head is about 20 feet below track level and the same distance below the level of the town well given above. The water flows about 5 or 6 gallons a minute. The following log was given from memory:

Log of well in southern part of Wickliffe, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay and gravel	12	12
Potter's clay (Lagrange)	130	142
Coarse sand, clear, yellowish, or reddish (Lagrange)	300	442
Blue marl or soapstone (Porters Creek)	158	600
Soft sand, water bearing (Ripley)	10	610
Blue marl with some kaolin, down to 1,000 feet depth (Ripley)	390	1,000
Flinty limestone (penetrated)	20	1,020

The present flow is from the 600-foot level. The water is largely used for drinking and has acquired the reputation of being very valuable for kidney diseases. An analysis by C. G. Heinrichs is as follows:

Analysis of water from well at Wickliffe, Ky.

[Analyst, C. G. Heinrichs.]

	Parts per million.
Silica (SiO_2)	7.3
Iron (Fe)	1.6
Calcium (Ca)	40
Magnesium (Mg)	11
Sodium (Na)	47
Carbonate radicle (CO_3)	87
Bicarbonate radicle (HCO_3)	48
Sulphate radicle (SO_4)	17
Chlorine (Cl)	24
	283
Free CO_2	41
Lithium	Strong trace.

A view of this well is given in Pl. VII, *A*.

CALLOWAY COUNTY.

Topography.—Calloway County is in the southeast corner of the Jackson Purchase region. Its southern border adjoins Tennessee, and its eastern boundary is Tennessee River. Its area is 402 square miles, of which about 350 are included in the area discussed here. The eastern portion along Blood River, adjoining the Tennessee Valley, is broken and hilly, and there are also hills on either side of the forks of Clarks River. Away from the neighborhood of the streams the surface is as a rule gently rolling. South of Murray there is a considerable area of "flatwoods" underlain and caused by the Porters Creek clay. The highest portion of the county is along the Tennessee line, where an elevation of about 600 feet is reached. The general slope is to the north. The average elevation of the county is from 500 to 525 feet. The lowest point is low water in the Tennessee at the northeast corner of the county, which is about 295 or 300 feet above the sea.

A. ARTESIAN WELL AT WICKLIFFE, KY.

B. LAGRANGE, LAFAYETTE, AND COLUMBIA FORMATIONS AT MAYFIELD, KY.

Geology.—The formations of the embayment portion of the county are the Ripley, Porters Creek, Lagrange, Lafayette, and Columbia loam. The Ripley consists of sands and clays and is exposed chiefly along Blood River and the upper part of Jonathans Creek, where the surficial formations are removed by stream erosion. It dips to the west beneath the Porters Creek. The leaden-colored clays and greensand of this formation are exposed along East and West forks of Clarks River and their tributaries. An excellent exposure showing numerous small interlacing sandstone dikes may be seen at low water on East Fork of Clarks River, between the highway and railroad bridges just south of town. West of the Porters Creek formation the sand and clays of the Lagrange are found in the western part of the county. All of the older formations are generally concealed, except along the streams, by the sand and gravel of the Lafayette. This gravel is in places, especially in the central and eastern parts of the county, 20 to 40 feet thick. An excellent exposure may be seen in the railway gravel pit just south of Murray. It is there a highly ferruginous, prevailingly orange-colored gravel, which is distinctly cross-bedded and has numerous sand pockets and some iron crusts in it. It shows 25 feet of gravel, overlain by 8 or 10 feet of sandy clay, with irregular gravel streaks through it in places. Above the Lafayette in many places are 5 or 10 feet of softer, leached-out or light-colored, sandy clay or loam that probably represents the Columbia and is the equivalent of the loess found along the Mississippi River bluffs to the west.

Water resources.—While there are numerous streams in the county, much of it is not well watered, and in dry seasons many of the small streams fail altogether. Ponds are widely used for stock. Underground water is reached in the stream valleys at depths of 20 to 30 feet, but on the uplands it is often 100 to 150 feet to permanent water, and in such places cisterns are usually used instead of wells. Water from the Porters Creek clay or "soapstone" is not good. This clay does not seem to be very thick in many places along its eastern margin, and it may there be dug or drilled through without difficulty. Under it good water should generally be obtained from the Ripley sand.

At Backusburg, in the valley of West Fork of Clarks River, there are numerous springs and shallow wells.

At Coldwater several large springs and wells that are 60 to 80 feet deep provide the water supply.

At Crossland cisterns are used almost exclusively on account of the depth to underground water.

At Dexter, elevation 424 feet, lying in a stream valley, water is obtained at a depth of 16 to 20 feet. On the neighboring uplands wells are 30 to 40 feet deep; many yield chalybeate water.

At Harris Grove water is struck usually at depths of 30 to 50 feet. One well 110 feet deep is a blowing well; during foul weather the wind rushes out strongly.

At Hazel a domestic supply is obtained from wells ranging from 30 to 60 feet in depth. The water is good and pure. Streams and ponds are used for stock.

At Lynngrove an abundant supply of soft water that contains some iron is obtained at a depth of 115 feet. Two wells—one 2-inch, the other 3-inch—were drilled there to a depth of 174 feet, and furnish excellent water from 115 feet depth. The log is as follows:

Log of well at Lynngrove, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay	15	15
Red clay	25	40
Gravel and sand	40	80
Red sand	10	90
Pottery clay	12	102
Yellow sand, with water at 115 feet	72	174

At Murray, elevation 480 feet, both wells and cisterns are used in about equal numbers. The wells used average about 30 or 40 feet in depth and are situated on low grounds or slopes near by. On higher ground water is deeper, a few wells being 100 feet deep, and the one in the court-house square 140 feet deep. The latter well goes through the surface soil, the Lafayette gravel, and the Porters Creek clay and gets water from the Ripley sand. In many places water may be obtained at the base of the Lafayette. If found in the Porters Creek it is hard and unfit to use. Wells are then usually abandoned, though it would be easy to sink them through this formation, as it seems to be from 5 to 30 feet thick only, and get water from the Ripley sand. In the uplands to the east of Murray very few wells are used, and in the corresponding area west of town the number is even less, cisterns being used in both areas because of the depth to water.

The Nashville, Chattanooga and St. Louis Railway dug a large brick well near the station to a depth of 73.6 feet and then sunk a pipe in the bottom of it to a total depth of 215 feet. The water rises to about 50 feet below the surface and stands about 23 feet in the large well. It is used for locomotives. The following log has been furnished by Mr. E. F. Doudna, of Mayfield, Ky.:

Log of well of Nashville, Chattanooga and St. Louis Railway at Murray, Ky.

		Thickness.	Depth.
		Feet.	*Feet.*
Sand, gravel, and clay		46.3	46.3
Quicksand		7.0	53.3
Clay, hard, black (Porters Creek)		20.0	73.3
Sand, slightly mixed with yellow clay	Ripley.	33.4	106.7
Bastard sand	Ripley.	28.0	134.7
Fine sand	Ripley.	5.0	139.7
Coarse sand and water	Ripley.	8.0	147.7
Shell of sand rock	Ripley.	3.0	150.7
Tough blue and black clay	Ripley.	15.0	165.7
Soapstone, slightly mixed with sand	Ripley.	16.0	181.7
Pure sand, fine	Ripley.	11.0	192.7
Hard shells of sand rock	Ripley.	1.5	194.2
Fine sand	Ripley.	3.5	197.7
Blue soapstone	Ripley.	1.0	198.7
Coarse dark sand with water	Ripley.	3.0	201.7
Coarse white sand with water	Ripley.	13.0	214.7

At New Concord water is struck in fine sand at a depth of 50 to 70 feet.

At Stella cisterns are used exclusively.

At Wadesboro water is obtained from springs along the foot of the hills and from wells back on the uplands that range from 20 to 60 feet in depth and furnish good water.

At Wetzel wells average about 50 feet deep. All contain more or less iron; cisterns are largely used.

CARLISLE COUNTY.

Topography.—Carlisle County is situated on the western edge of the Jackson Purchase region, almost midway between its northern and southern extremes. Its western boundary is formed by Mississippi River and its northern boundary is Mayfield Creek. Its area is 188 square miles. Along its western border there is a fringe of Mississippi bottom of varying width. The eastern margin of this bottom is formed by a bluff that rises from 75 to 150 feet above it. Eastward from the bluff the general upland, which includes all of the remainder of the county, has a rolling surface. The upland slopes slightly to the northwest and has an average elevation of about 400 feet. Low water in the Mississippi is about 275 feet and high water about 315 feet.

Geology.—The formations are the Lagrange, the Lafayette, the loess, and the alluvium. The Lagrange consists of light-colored sands and clays, with occasional beds of lignite. It is exposed along the bluffs and in occasional stream cuttings. On the upland surface the Lafayette sand and gravel, 10 to 30 feet thick, rests on the Lagrange. The bluffs overlooking the alluvial region are capped by the loess, which rests on the Lafayette and may be 20 to 50 or 60 feet thick near the bluffs, but gradually thins out to the east and merges into

a surface loam. The surface of the Mississippi bottoms is composed of Recent alluvium.

Water resources.—There are numerous streams in the county which flow into Mississippi River, Mayfield Creek, and Obion Creek. The smaller of these streams may go dry in the fall. The larger ones are permanent. For domestic purposes cisterns are largely used in the loess region, because of the hardness of the shallow water. They are also used in the middle and eastern parts of the county in places where the depth to underground water is inconveniently great. The average depth of wells on the uplands may be taken at from 60 to 100 feet. Water may be obtained at any point from the Lagrange. For a supply sufficient for domestic or boiler use it would not usually be necessary to go more than 150 or 200 feet, the depth in any one case depending on the coarseness of the sand. For town supply it might be advisable to explore the deeper beds, as there is usually no difficulty in pulling a pipe back in case a better supply is not found at the greater depth. Along Mayfield and Obion creeks bold springs of pure, cold water from the Lagrange sands occur. Back on the uplands weak springs, in which the water is not so pure nor so cold, are found in local depressions here and there. As a rule they are used for watering stock only, and some of them go dry in late summer.

At Arlington open wells from 30 to 50 feet deep afford a limited supply of water. If larger quantities are wanted, for manufacturing or other purposes, it is necessary to go considerably deeper. Several wells for boiler supply are reported to be 120 feet deep, but in the log given below lignitic clay occurs at this level. One well is reported to be 228 feet deep, with water rising within 12 feet of the surface. It furnishes all the water that can be raised by a suction pump with a capacity of 400 gallons a minute, located on the surface. The log, given from memory, is as follows:

Log of well at Arlington, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess	50	50
Orange sand and gravel with clay	12	62
Brown clay, lignitic	133	195
White water-bearing sand	33	228

At Bardwell, elevation 357 feet, there are numerous ordinary wells. The town waterworks gets a supply from two wells reported to be about 250 feet deep. The Illinois Central Railroad has two wells that furnish an abundance of water for all railroad purposes. The following log of these two wells was given from memory:

Log of Illinois Central Railroad wells at Bardwell, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	100	100
Sand and blue clay in alternate strata, individual beds of sand being not over about 6 feet thick	523	623

The pipe was pulled back and a 20-foot strainer set at 120 feet from the surface. The water rises within about 30 feet of the surface and is soft and excellent for all purposes. The elevation of the well head is about 386 feet, 4 feet lower than the railroad level given above.

At Cunningham bored wells are used very largely.

At Laketon, elevation 314 feet, there is a well owned by the Mobile and Ohio Railroad which furnishes from the Lagrange an excellent water for locomotive use. Detailed data could not be procured.

At Milburn water is obtained from open and bored wells that range in depth from 20 to 60 feet. The quality of the water is good. There are very few springs.

FULTON COUNTY.

Topography.—Fulton County is in the extreme southwestern part of Kentucky. It is bounded on the south by Tennessee and on the west by Mississippi River. Its area is 178 square miles. Something more than a third of the county is in the alluvial region of Mississippi and Bayou de Chien rivers and Obion Creek. This portion is low and flat, its average elevation being about 290 feet. The remainder of the county, extending from Hickman southward and eastward, is a level to rolling upland whose western and northwestern borders are hilly or bluff-like. The bluff at Hickman rises to an elevation of 461 feet and may be the highest point in the county. Low water in the Mississippi at Hickman is 257 feet and high water 303 feet. The average elevation of the upland is about 400 feet.

Geology.—The formations of this county are the Lagrange, the Lafayette, the loess, and the alluvium. Their relationships are exactly the same as in Carlisle County (p. 129). The Lagrange has in this county, however, a greater amount of fine siliceous clay than usual. The best exposures are in the bluff at Hickman, a section of which is given on page 37. This section has been discussed so fully on pages 37–9 that repetition is not necessary here.

Water resources.—Springs along the bluffs are usually strong and yield either pure or chalybeate water. Elsewhere they are weak. Wells in the alluvium are shallow, as usual, and furnish poor water. On the uplands water may be reached in sufficient quantities for domestic use at depths of 40 to 100 feet. When obtained at slight depth it is apt to be hard. The Lagrange contains comparatively

few beds of water-bearing sand coarse enough to set a strainer in and hence difficulty is experienced in some places in making a satisfactory deep well in it. A log of such a well is given under Hickman (p. 133). The streams on the uplands are all small and some go dry at times, so that in places ponds or wells must be used for stock water.

At Fulton, elevation 366 feet, water is obtained at depths ranging from 25 to 100 feet. There is a system of waterworks supplied by several wells, each 100 feet deep. The quality of the water is medium. It is used for general domestic purposes and also by the Illinois Central Railroad in locomotives. Between 600,000 and 700,000 gallons per day may be pumped. The log is as follows:

Log of Illinois Central Railroad well at Fulton, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay	25	25
Shell of rock	¾	25¾
Sand	22 ±	47¾ ±
Yellow clay	23	70 ±
Coarse, white water-bearing sand (entered)	30	100 ±

At Hickman, elevation of low water, 275 feet; high water, 303 feet; railway, 306 feet; top of bluff, 461 feet, water is obtained from ordinary wells and from cisterns to some extent. A waterworks plant has been built, and water is pumped to a standpipe on top of the bluffs, from which it flows into the mains.

Capt. H. A. Tyler has a deep well on the upland near town, 130 feet above high-water mark, or 433 feet above sea level. The water rises within 110 feet of the surface. It is soft and good for washing or boiler purposes. It contains some iron. Two logs were given. The first, by Captain Tyler, is as follows:

Log of Tyler well near Hickman, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay (loess)	80	80
Soft sandstone (Lafayette)	10	90
Blue clay	460	550
Very fine sand	6	556
Tough blue clay	144	700
White water-bearing sand (entered)	17	717

A 20-foot strainer point was set at 717 feet. The well is 6 inches in diameter, and 5,400 gallons per hour may be pumped. Another driller had previously gone to a depth of 830 feet within 10 feet of this well, but the pipe was telescoped. From 717 to 830 feet the section is reported to be mostly sand, with a little clay.

The second log is by Mr. W. B. Johnson, of Johnson & Flemming, the drillers. It is as follows:

Log of Tyler well, near Hickman, Ky., given by drillers.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess	80	80
Orange sand and gravel	30	110
White sand and gravel, traces of clay	165	275
Blue clay	182	457
Hard rock	6	463
Blue clay	157	620
White pipe-clay	80	700
Coarse water-bearing sand	17	717

The well was successfully finished at this depth.

It is interesting in this connection to be able to compare these logs with that given by Mr. W. F. Crosby, of Crosby & Co., the drillers of the well 10 feet distant, in which the pipe was telescoped at 830 feet, in order to see how three records of the same section, all given from memory, compare. It is as follows:

Log of drill hole at Hickman, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay and sand	200	200
Quicksand	30	230
Blue and brown gumbo clay, lignitic	280	510
White chalky substance with a fine vein of water just under it, not tested	40	550
Blue gumbo clay, lignitic, as above	150	700
Sand	160	860

A comparison shows that while there is agreement in that the larger part of each section is lignitic clay, and water-bearing sand was reached at a depth of 700 feet, there is considerable difference in details, and this may often be true where records are given from memory. Men who make a business of drilling wells would undoubtedly find it to their own advantage to keep careful logs of all wells drilled, especially when drilling in sands and clays so variable in thickness that memory can not be depended on to preserve the details of the various sections.

In a valley 3½ miles somewhat north of east from Hickman, at an elevation estimated to be about 30 feet above high-water mark (about 333 feet above tide), a well was drilled on Mr. R. A. Tyler's stock farm. The water is hard, and rises within 30 feet of the surface. The log is as follows:

Log of well on R. A. Tyler farm, near Hickman, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay with small iron nodules (loess with buckshot)	57	57
Gray-black quicksand with lignite	53	110
Coarse white water-bearing sand, parted by very thin strata of white pipe clay.	82	192

Near Hickman is the Nick Combs mineral spring, which is discussed on page 145.

At Jordan, elevation 398 feet, water is obtained from wells and cisterns. Wells vary from 35 to 110 feet. Water is most abundant at 100 feet, and is reported to be hard.

GRAVES COUNTY.

Topography.—Graves County is quadrangular, its long dimension extending north and south. It is situated in the middle of the Jackson Purchase region from east to west and extends from the Tennessee line more than two-thirds of the way to Ohio River. It is the largest of the Kentucky counties here discussed, its area being 550 square miles. The surface slopes gently to the northwest. It may be described as level to rolling away from the main drainage lines and hilly along them. Especially on the eastern (right-hand) side of West Fork of Clarks River and Mayfield Creek, the two principal streams of the county, the valley wall rises steeply to the upland level. On the western side of each stream, however, the ascent to the general upland level is not abrupt, but gradual. The highest point in the county and also in the Jackson Purchase region, according to Loughridge, is in the southern portion, about halfway between Lynnville and Pilot Oak. Its elevation is given by Loughridge as 625 feet. The average elevation of the southern part of the county is about 550 feet. The slight northwestward slope makes the elevation of the northern part of the county about 425 or 450 feet. The lowest point is about 320 feet, where West Fork of Clarks River leaves the county.

Geology.—The geologic formations of the county are the Porters Creek, Lagrange, Lafayette, and Columbia loam. The Porters Creek is confined to the northeastern part of the county and is concealed by the Lafayette except where the latter has been removed by erosion along West Fork of Clarks River. It has its typical character, being a dark leaden-colored clay, usually called soapstone, with occasional silty or sandy beds. The clays in many places are cut by sandstone dikes, as has been described at some length on page 30. The thickness of this clay is probably not over 125 or 150 feet. It dips westward beneath the Lagrange.

The Lagrange underlies all of the county except the Porters Creek area just mentioned. It also is concealed by the Lafayette except in stream or other cuttings. It consists of light-colored sands and clays, some of which are dark with lignitic matter, while others are white and plastic and are mined for pottery making.

The Lafayette is well developed as an orange-colored sand, grading down into or underlain by a gravel bed which forms its basal portion. This gravel is highly ferruginous as a rule.

On the uplands the Columbia loam rests on the Lafayette. It is a light-colored sand beneath, usually soft and containing a few pebbles derived from the Lafayette, and grades up into a loam, the entire thickness being 5 to 10 feet. A most excellent exposure is seen in the town gravel pit just east of the railroad track in the southern part of Mayfield. Pl. VII, *B* (p. 126), is a view of this pit. It shows at the base 18 feet of soft variegated and cross-bedded Lagrange sand. Over it, with a sharp contact line between them, are 20 to 22 feet of Lafayette gravel. It has much sand intermixed and some thin iron crusts and stands well in vertical faces. The gravel is principally chert, though there are some pieces of vein quartz. It is used for road material and is being removed in two benches, which are well shown in the plate. Over this and separated by a sharp but irregular line are 10 feet of material that is lighter in color and softer, so that it does not stand up with vertical faces so readily. The lower 3 or 4 feet of it are chert and vein-quartz pebbles, similar in size and rounding to the Lafayette pebbles below, from which they were undoubtedly derived. The slight reworking to which they have been subjected has deprived them of their iron and of their bright color and given them a leached appearance. They grade upward into sand and the sand into surface loam, both of which have the same light-brown or leached color, which readily serves to differentiate this deposit from the Lafayette beneath. It is the representative of the Columbia. In the plate it is the upper bench extending to the top of the pit.

Water resources.—Except along the stream valleys, springs are few and generally weak. The small streams have in consequence weak flows, and the great majority of them go dry in late summer. West Fork of Clarks River runs all the year. Everyone has ponds for stock. Along the stream valleys water may generally be reached in wells 20 to 30 feet deep. On the uplands in the southern, central, and northeastern parts of the county wells are 60 to 125 feet deep, and in some places do not then reach water. In the northwestern part of the county the average depth to water is somewhat less. Cisterns are largely used.

It should be possible to get good water in the "soapstone" or Porters Creek area by going through it into the Ripley sand beneath. In the Lagrange area good water may be obtained almost anywhere at depths of 200 to 400 feet. Because of the great average elevation of the county, water will not rise to the surface, and, indeed, in most of the county there will probably be little if any rise at all. Shallower water is found at the base of the Lafayette in places where there is enough hardpan to make an impervious basin. Such wells are weak and are apt to fail in dry seasons, and are in addition fed by surface rain water, and so liable to contamination.

At Bloom there are a few springs, but water is generally obtained from cisterns.

At Cuba water is obtained from wells that are from 100 to 150 feet deep; cisterns are largely used.

There are some good springs in the neighborhood of Dublin, but no wells. Cisterns are used.

At Fancyfarm the supply has come from cisterns chiefly, but small tubular wells, some of which are 120 or 130 feet deep, are coming into use. They furnish good, pure water from the Lagrange sand. In low places wells are less than 50 feet in depth.

At Farmington cisterns are used almost exclusively because of the depth to underground water. There are a few small tubular wells 120 to 165 feet deep.

At Folsomdale there are a few wells, but cisterns are almost universally used.

At Freda there is only one well. It is 90 feet deep and is not used. There are a few springs. Cisterns are used by all.

At Golo cisterns are used almost exclusively. The few wells and springs are used for watering stock.

At Lowes water is obtained mostly from cisterns. There are only a few wells and they average 100 feet or more in depth.

At Lynnville cisterns are used almost exclusively. A blue clay is struck very near the surface and few of the attempts at boring wells are successful. It is probable that a well sunk 100 or 150 feet would go through this blue clay and find water-bearing sand in the Lagrange. Such clay beds in the Lagrange are not usually over 100 or 150 feet thick.

At Mayfield, elevation 480 feet, underground water is struck at a depth of 90 or 100 feet, and cisterns have been largely used there and in the surrounding country, where the same conditions as to depth to water prevail. A system of waterworks has been installed by a private corporation, which has one 10-inch well 304 feet deep, one 8-inch well 300 feet deep, and two 8-inch wells 160 feet deep. The water stands in them at about 80 or 90 feet from the surface. It is pure and clear and is raised by air lift to the surface and then forced into a standpipe. Only one well is pumped at a time. The average daily consumption is about 250,000 gallons. The following log was given by the driller, Mr. W. B. Johnson, of Johnson & Flemming:

Log of well at Mayfield, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay, like loess	12	12
Orange sand and gravel, dry	60	72
Orange sand and gravel, water bearing	218	290
Thin parting of pipe clay at		290
White water-bearing sand	50	340

At Pryorsburg, elevation 420 feet, water is obtained from wells 30 to 40 feet deep and from cisterns.

At Ragsdale cisterns are used principally. Wells are scarce.

At Sedalia six wells of small diameter from 120 to 170 feet deep furnish a very pure water. Cisterns are largely used.

At Symsonia there are no wells or springs of any note. Cisterns are used.

At Tice cisterns are used almost exclusively. There are a few wells 30 to 75 feet deep.

At Viola, in the valley of Mayfield Creek, wells are 18 to 75 feet deep; most of them are bored and the water has more or less iron in it.

At Vultoncreek water is obtained from cisterns for domestic use and from ponds for stock. The few springs go dry in summer. There are no wells in the vicinity.

At Water Valley, elevation 386 feet, wells are used principally. They range from 25 to 40 feet in depth. Cisterns are also used to a considerable extent. A mineral well is noted on page 146.

HICKMAN COUNTY.

Topography.—Hickman is one of the western tier of counties and reaches on its western side Mississippi River and on its southern side the Tennessee State line. Its area is 224 square miles. Along the Mississippi and the lower course of Obion Creek within the county there is a small area of low alluvial land. The remainder of the county is a level or rolling upland in the interstream areas, which becomes broken and hilly along the main streams and near the bluffs that overlook the Mississippi flood plain. The average elevation of the upland is about 375 feet and of the alluvial region about 310 feet. Low water in the Mississippi is 260 to 270 feet. The upland slopes gently westward and is drained by Bayou de Chien and Obion Creek into the Mississippi.

Geology.—The geology of the county is the same as that of Carlisle County on the north and Fulton County on the south. The underlying formation is everywhere the Lagrange sand. It is admirably exposed at Chalk Bluff below Columbus and at Columbus. At the latter place about 80 feet of it may be seen forming the base of the bluff, the upper part being a grayish, somewhat jointed clay resembling slightly the clay so prominent in the middle and upper parts of the bluff at Hickman.

Over the Lagrange are 35 feet of Lafayette in the Columbus bluff, the lower 20 feet being gravel and the upper 15 feet a sand at the base, which grades up into a gravel at the top. Eastward from the bluff the Lafayette is as a rule not so thick and is not so heavily charged with gravel.

Along the bluffs facing the Mississippi the loess overlies the Lafayette. The lower part is usually darker than the upper, as described on page 45. The thickness may reach 60 or 80 feet. To the east it thins down and merges into the surface loam.

The alluvium rests on the Lagrange in the river and creek bottoms. It is believed to be of Recent origin.

Water resources.—Streams are numerous and the larger ones flow perennially. Along their valley sides springs are found, but their situation generally precludes their use for domestic supply. Along with the streams and scattered artificial ponds they are used for stock watering. In the alluvial region water of medium quality is obtained at depths of a few to a score feet. Back on the uplands wells vary considerably in depth, but often go 75 or 100 feet. Cisterns are used in many places because of the hardness of the water in the loess area or the depth to it elsewhere. Good water may be gotten in the Lagrange at moderate depths, and small driven wells should be found practicable at any point where difficulty is encountered in obtaining a satisfactory supply.

At Clinton—elevation at Illinois Central Railroad 354 feet, at courthouse 389 feet—there are numerous bored wells 100 to 150 feet deep. The town supply is obtained from two wells that draw their water from white sand 135 or 140 feet deep. It is reported to be hard and to contain iron. The water stands within 30 feet of the surface.

At Columbus water is obtained from shallow wells and cisterns. Factories get their boiler supply from Mississippi River.

Moscow, elevation 313 feet, derives most of its water supply from ordinary wells 40 to 60 feet deep. There are a few pipe wells 80 to 130 feet deep. Both kinds furnish good pure water.

At Oakton, elevation 315 feet, there are a number of pipe wells 75 to 125 feet deep that furnish supplies for domestic and boiler use.

At Springhill hard water is struck at an average depth of 60 feet. Wells in the neighborhood range in depth from 25 to 200 feet. Cisterns are used almost exclusively.

At Stubbs hard water is obtained in wells 20 to 40 feet deep and water of better quality, though frequently containing some iron, in wells 80 to 130 feet deep.

M'CRACKEN COUNTY.

Topography.—McCracken is the eastern of the two northern counties of the Jackson Purchase region. Its northern and northeastern boundaries are Ohio and Tennessee rivers. Its area is 241 square miles. Topographically, there is a threefold division of the surface, just as in Ballard County (p. 122). Along Ohio and Tennessee rivers there is a narrow strip of alluvial flood plain whose elevation on the eastern edge of the county, along the Tennessee, is about 325 feet,

and in the northwest corner, on the Ohio, about 315 feet. This flood-plain belt is in many places very narrow. Lying just south of the flood-plain belt is a second bottom or terrace 25 to 35 feet higher than the first bottom. It has an average width of 3 or 4 miles and extends up Clarks River and its east and west forks to a point beyond the county line. It embraces an area of about 85 square miles. At Paducah, which is built upon it, it is well developed and has an elevation of 340 feet. Its surface is level except near the streams which cross it and have trenched their channels 15 to 25 feet beneath its surface. The remainder of the county is an upland region with a rolling surface that is almost level in the interstream areas and considerably broken near the streams that drain it. The general upland slope is slightly northward and its average elevation is not far from 400 feet.

Geology.—The Ripley, Porters Creek, Lagrange, Lafayette, Columbia, and Recent alluvium all occur within the county. The Ripley underlies a strip along the eastern edge and is exposed here and there along Clarks River and on the Tennessee at low water as far north perhaps as Paducah, though at the latter place the writer failed to find any exposures. In the deep well at Paducah, a log of which is given on page 141, it was struck at a depth of 60 feet and is a soft sand with a number of clay lenses that are usually lignitic where seen in the surface exposures in the vicinity.

The Porters Creek overlies the Ripley and in the southeast corner of the county is exposed at intervals along both forks of Clarks River and for some distance down the main stream. It is well exposed on two hills 3 and 4 miles, respectively, south of Paducah, on the road to Mayfield, where it consists of joint clay and silty sand, the latter partly indurated and containing casts of Eocene fossils. Northwest of Paducah it probably underlies most, if not all, of the second bottom as well as the northern edge of the upland, though it is almost entirely concealed by later deposits. Its thickness is about 150 feet.

The Lagrange underlies the central and southwestern parts of the county, but is not exposed except along the deeper stream cuttings. It has its usual character, being a light-colored sand interbedded with occasional clays that are either white or more or less lignitic.

The red Lafayette sand and gravel overlies the Lagrange and the Porters Creek on the upland. It is somewhat uncertain whether it should be regarded as present on the old terrace level or not, but the writer is inclined to think that the gravel and overlying sand and clay on this terrace are not so old as the Lafayette and should more properly be classed as part of the Columbia. At Paducah this terrace has on the surface from a few feet to 30 or 40 feet of silty sand and clay, and beneath it a hard "cement gravel," as it is popularly known, 20 to 30 or more feet thick, with pebbles up to 4 or 5 inches in diameter.

The terrace is cut distinctly beneath the Lafayette-capped upland, and its pebbles are larger than those of the near-by Lafayette gravels, so that it seems younger than the Lafayette.

A few feet of Columbia sand and surface loam overlie the Lafayette and form the actual surface of the upland.

The alluvium is a very narrow strip along Tennessee and Ohio rivers, and is regarded by the writer as entirely Recent in origin. It has been correlated with the Port Hudson, but reasons have been given on page 49 for believing that the Port Hudson does not extend so far north.

Water resources.—There are a number of permanent streams in the county. Clarks River crosses the east end and Mayfield Creek the southwestern part, while a number of small streams rise in the county and flow northward into the Ohio or the Tennessee. Along these streams springs are numerous, but they are utilized to only a limited extent. Most of the water supply of the county is from wells and cisterns. In the terrace belt the water found in the underlying gravel is hard, and the silty material over it is not firm enough to keep cistern walls from cracking and letting water seep into them. In this area exploration for deeper waters should be made. In most places within it the dark Porters Creek clay will probably be found beneath the terrace gravel. This should be drilled through and careful watch kept for a bed of sand in the underlying Ripley coarse enough to be checked by a strainer. If this is not found, the bottom of the Ripley should be reached at a depth of 300 to 400 feet or less, and water would probably be found there or in the broken Paleozoic chert that underlies the embayment deposits in this region. On the uplands wells go from 20 to 150 feet before reaching underground water, and in many places cisterns are used instead.

At Grahamville water is obtained almost entirely from drilled wells. It is said to be very satisfactory as to quality and quantity. There are very few cisterns and practically no springs.

At Massac water is struck in sand at depths of 100 to 120 feet.

At Maxonmill there are a number of fine springs. Wells average from 20 to 40 feet deep and are either bored or dug. One dug in the flats of Massac Creek and described by Loughridge[a] reached the Porters Creek clay at 18 feet from the surface and passed through it and into Ripley sand at a depth of 116 feet, when the water rose 60 feet, but contained so much sulphureted hydrogen that it was unfit for use.

Paducah, elevation of low water 284 feet, high water 334 feet, average town elevation about 341 feet, is underlain by from a few feet to 30 or 40 feet of silty material and that by 20 or 30 feet of rounded gravel in which water is abundant but hard and chalybeate, besides

[a] Jackson Purchase Region, 1888, p. 253.

being probably contaminated by organic matter from the surface. Numerous cisterns have been built, but they almost invariably settle somewhat and crack enough to let in seepage water. The city water supply is pumped from Ohio River into a standpipe that gives a pressure of 40 pounds, which, in case of fire, is increased to 100 pounds by direct pressure. The daily consumption is about 2,200,000 gallons.

A well at the old vinegar works has the following log:[a]

Log of well at vinegar works, Paducah, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Loam or heavy yellowish clays	30	30
Gravel	10	40
Blackish-blue clay	8	48
Colored sand	6	54
Blackish-blue clay	8	62
Fine white sand to water	50	112

A well was bored about 1888 at Paducah for gas and abandoned at a depth of 1,250 feet. The log, as given by Loughridge,[b] is as follows:

Log of boring for gas at Paducah, Ky.

	Thickness.	Depth.
Post Lafayette:	*Feet.*	*Feet.*
Micaceous brownish surface loam	40	40
Rounded chert and quartz gravel	20	60
Ripley:		
Fine micaceous sand and clay, interlaminated	204	264
Mississippian:		
Débris of white and dark chert, hyaline sand, pyrites, and smoky-quartz crystals. The lower 18 feet is cemented by a bright-red iron ocher, and holds numerous crinoids, bryozoa, and plates and spines of the echinoid *Archæocidaris*	71	335
White, porous, and slightly calcareous rock; also containing many crinoids, bryozoa, and echinoids	90	425
Dark impure limestone, with some crinoids and bryozoa, fragments of cemented calcareous material, and a small flat mass of quartz crystals; the rock is cavernous	45	470
Limestone and siliceous rock, dark and light colored; some calc spar; crinoids, cyathophylloid corals, and pyrites in lower portion; rock is cavernous	48	518
Dark calcareous shale, blue marl, and sand, with small crinoids, spines, and plates of *Archæocidaris*, and cyathophylloid corals	32	550
White calcareous shale, with calc spar, pyrites, and a few crinoids	185	735
Blue limestone, with crinoids; a pentremite brought up from upper portion	400	1,135
Blue limestone, with crinoids; this bed, with the lower portion of that above, is permeated with cracks filled with sand, etc., to bottom of boring	115	1,250

At Ragland a water supply is derived from wells which range from 35 to 65 feet in depth.

Woodville, elevation 423 feet, depends mainly on cisterns. A few 2-inch wells go about 140 feet deep and get water from sand. It contains some iron. The log is as follows:

[a] Loughridge, R. H., op. cit., p. 250.

[b] Op. cit., pp. 321-326.

Log of well at Woodville, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	17	17
Cement gravel	23	40
Loose gravel	20	60
White chalk	2	62
Sand, bowlders, and streaks of pipe clay	25	87
Sand, red at top, then yellow, then white	57	144

MARSHALL COUNTY.

Topography.—The northern and eastern boundaries of Marshall County are formed by Tennessee River. Its area is 332 square miles. Along the Tennessee there is a very narrow flood plain. Rising 25 to 35 feet above it is an old flood plain or terrace from 1 to 2 miles in width, which is merely a continuation of the terrace noted along Ohio River in Ballard and McCracken counties and which has an elevation in the northwestern part of the county of about 340 feet and in the southeastern part of about 350 feet. This same old terrace level forms the valley of East Fork of Clarks River, which flows northwestward across the middle part of the county. This valley has an average width of a mile or more. The remainder of the county is an upland which is almost level in the parts remote from streams, but which, especially along the border adjacent to the Tennessee River Valley, is hilly and much broken by the numerous small streams flowing into the Tennessee. It is also somewhat broken along either side of the valley of East Fork of Clarks River. The upland slopes gently northward and nearly all of the drainage is northward. Its average elevation is between 425 and 450 feet.

Geology.—A strip of Paleozoic limestone lying along the eastern side of the county has a width of 4 to 6 miles west of Tennessee River. Only the portion of the county west of this strip belongs to the embayment region. The formations represented in it are the Ripley, Porters Creek, Lafayette, Columbia, and alluvium.

The Ripley extends from the valley of East Fork of Clarks River eastward to the Paleozoic area and forms a belt about 4 miles wide in the southern part of the county and 6 miles wide in the northern part. It consists of fine micaceous sands and interlaminated dark-gray clays that contain lignitic matter in places. Excellent exposures may be seen at Snow Hill, on the eastern side of Clarks River Valley, along the road from Benton to Briensburg. Away from the stream cuttings the Ripley is concealed by the overlying gravels and sandy clay belonging to the Lafayette and Columbia, but is reached on the upland east of Clarks River at depths of 40 to 50 feet in wells. The thickness of the formation here is not known, but is probably between 200 and 300 feet.

The Porters Creek clay overlies the Ripley on the east and extends from East Fork of Clarks River westward across the remainder of the county. It is, as usual, a joint clay and is almost black when wet, but light gray when dry. With it there are some greensand and some fine silty sand, which is usually indurated into a sandstone or mudstone. It is exposed only along the stream valleys. The writer had no opportunity to examine its outcrop west of West Fork of Clarks River, but accepts its presence there as far west as Pritchard, Graves County, on the authority of Loughridge. Along and east of West Fork it is typically developed. The Porters Creek belt is peculiar in this region in being much broader in surface exposure than it is elsewhere in Kentucky or Tennessee. The width reached is 12 or 14 miles.

The Lafayette has at its base a variable thickness of gravel, which grows heavier, as a rule, to the east and is in many places cemented into an ironstone conglomerate. Above the gravel there are usually 10 or 15 feet of red sand or sandy clay, which also belongs to the Lafayette. This is usually overlain by a few feet of leached surface clay or loam that probably represents the Columbia. In places this loam has some reworked gravel at its base. The Lafayette and Columbia together usually have an aggregate thickness of 30 to 40 feet, and on the uplands completely conceal the underlying formations.

Water resources.—While the larger streams flow the year round, many of the smaller ones go dry in the fall. Springs are numerous along the stream valleys, but elsewhere are scarce or entirely absent. Ponds are used in many places for watering stock. The domestic supply is derived from wells and cisterns, the latter being perhaps the more common. Water may generally be obtained along the valleys at depths of 20 to 40 feet and on the upland at 35 to 40 feet in many places at the base of the Lafayette. Wells often go dry in the summer, and there seems to be a general impression that since the 1886 earthquake they have been more liable to go dry than before. This same opinion has been met with elsewhere in the region, but nowhere was it found so strong as in this county. It is probable that this earthquake may have produced slight cracks in the hardpan ironstone crusts which locally form water-containing basins at the base of the Lafayette and that the downward seepage through these cracks is great enough to cause the basins to be more readily drained during dry seasons than formerly, and hence to cause the wells to go dry more readily. Where a well failed altogether after the earthquake, it would seem evident that the fissures produced were so large that the local basin could no longer hold water, but was drained down into the dry sands beneath.

In the region underlain by the Porters Creek if water is not struck

at the base of the overlying Lafayette the well is generally abandoned and a cistern dug. In many places farms have both wells and cisterns. On the uplands east of East Fork of Clarks River the depth to water in the Ripley sand is in many places 60 to 100 feet or more, and in much of that region cisterns are used exclusively for domestic supply and ponds for stock.

At Benton, elevation 368 feet, water is obtained mostly from cisterns. Wells are often dug and in some places reach water at a depth of 35 or 40 feet above the black or dark-gray Porters Creek clay. Such wells prove satisfactory. If this clay, usually described as a black or blue mud, is encountered, the well is abandoned, as water from it is hard and astringent.

In the country west of Benton wells average 35 to 40 feet deep and get water at or just above the base of the Lafayette gravel. Such water is in some wells found to be hard and in others soft. The supply is usually limited, and the well may go dry in late summer. In other places no water is obtained above the Porters Creek clay, and resort is had to cisterns. These are perhaps scarcely as numerous as wells. Probably 40 or 45 per cent of the people use them, while many have both cisterns and wells.

Brewer is well supplied with ordinary wells of 30 to 50 feet depth and springs which bubble out along the foot of the hills bordering the valley of West Fork of Clarks River.

At Briensburg cisterns are used exclusively. In the country around cisterns are the common source of supply. Wells are rare because of the depth to the Ripley sand and the uncertainty of getting water in it.

At Coy water is supplied by wells 30 or 40 feet deep.

At Fairdealing there are a few springs, and some wells that average 35 to 50 feet deep, but furnish only a small amount of water. Most people have cisterns. The springs are at the foot of bluffs along streams, and are mostly chalybeate.

At Fristoe, elevation 352 feet, there are no wells or springs; cisterns are used. From its location in the valley of Clarks River, it should be an easy matter to bore or drive a well through the "soapstone" or Porters Creek clay. While much of the Ripley sand is too fine to be water bearing, yet some beds are usually found in it coarse enough to hold an abundance of water, and as a test with a driven well is not expensive, it would be well worth making.

At Harvey water is obtained from wells 25 to 50 feet deep. In some places the Porters Creek clay is struck before water is reached, and then the well is abandoned and a cistern substituted. In the country just north of Harvey cisterns are used exclusively. Wells do not go dry, but usually have weak flows. Some yield hard water and some soft, according to the nearness or remoteness ot the underlying Porters Creek clay.

At Oaklevel water is obtained entirely from shallow wells.

At Palma cisterns are used almost exclusively.

At Paul there are a few springs, but the main water supply is obtained from wells 50 to 75 feet deep.

At Scale there are numerous springs, wells, and cisterns. Wells in low places run about 20 feet deep; on high ground they are 50 to 60 feet. Springs are considerably used for domestic supply.

At Tatumsville cisterns are used almost exclusively for domestic supply and ponds for watering stock.

MINERAL WATERS OF WESTERN KENTUCKY.

Britts Spring, at Stubblefield, Graves County, flows from the bottom of a bluff near a creek and forms along its course a reddish or yellowish deposit of iron hydrate, such as is so characteristic of chalybeate waters. The water is reported by the owner to contain 314 parts per million of solid matter, mainly carbonates of iron and calcium. It has some carbonate of magnesia, traces of the sulphates and chlorides of sodium, potassium, and magnesium, and a good deal of organic matter. It is said to be beneficial in malarial and stomach troubles.

Nick Combs Spring is at the foot of the Mississippi River bluffs, 4 miles southwest of Hickman, Fulton County. There are no hotel accommodations, but the spring has long been known, and people afflicted with kidney or stomach troubles go there in the summer and camp out. The water is chalybeate. Rheumatism, especially, is said to be benefited by its use. Dr. Robert Porter, chemist of the Kentucky Geological Survey, reports[a] it to contain free carbonic acid and 302 parts per million of salts. "These consist of iron, manganese, lime, and magnesia carbonates, with some lime and magnesia sulphates."

Kilgore Spring, 2 miles south of Blandville, Ballard County, is reported by Doctor Peter, as quoted by Loughridge, to yield a slightly chalybeate and alkaline saline water and to contain 64 parts per million of solids. These consist of carbonates, chlorides, and sulphates of iron, soda, lime, and magnesia, with a trace of lithia and some silica.

McGee Spring, on Hurricane Creek, southeast of Blandville, Ballard County, is reported by Doctor Peter to give a good alkaline saline chalybeate water containing 1,645 parts per million of solids and only a trace of organic matter. His analysis is as follows:[b]

[a] Loughridge, R. H., Jackson Purchase Region, 1888, p. 137.

[b] Loughridge, op. cit., p. 138.

Analysis of water from McGee Spring, Ballard County, Ky.

	Parts per million.
Silica (SiO_2)	240
Iron (Fe)	182
Calcium (Ca)	67
Magnesium (Mg)	47
Sodium (Na)	244
Potassium (K)	50
Carbonate radicle (CO_3)	590
Sulphate radicle (SO_4)	62
Chlorine (Cl)	163
	1,645

At Sedalia, Graves County, there is a mineral well 133 feet deep at which a hotel has been erected for the accommodation of guests. An analysis of the water by A. M. Peter shows it to contain 77.1 parts per million of solids, "nearly half of which is organic, the rest consisting of carbonate of iron and silica, with small quantities of carbonates, sulphates, and chlorides of calcium, magnesium, and sodium and traces of potassium and lithium compounds."

Water Valley well, at Water Valley, Graves County, yields a sulphate saline water containing, according to an analysis by A. M. Peter, 3,422 parts per million of solids, composed of sulphates of calcium, magnesium, and manganese, a little chloride of sodium, and traces of the sulphates of strontium, potassium, and lithium, and having a decidedly acid reaction. It is recommended especially in diseases of the stomach, liver, kidney, and bowels.

The water from Wickliffe artesian well, at Wickliffe, Ballard County, a description and analysis of which are given on page 125, has earned a reputation of being very valuable in kidney disorders, having made, as reported, remarkable cures in some serious cases.

RESOURCES OF SOUTHERN ILLINOIS.

Area included.—The Cretaceous and Eocene embayment deposits in Illinois are confined to Alexander, Massac, Pulaski, and Pope counties, in the extreme southern part of the State. Later surficial deposits of gravels, loess, and loam extend beyond these counties, but do not present hydrographic problems that would warrant their inclusion and discussion here. Since observations were not made in as much detail here as elsewhere, these counties will not be discussed separately, but all the data obtained will be given together.

Because of the presence of the loess, Lafayette, or alluvium over almost the entire embayment area of southern Illinois, it is difficult to give accurately the outlines of the area so included. The boundary may, however, be approximately traced as follows: Beginning on the east at New Liberty, on Ohio River in Pope County, the edge of the embayment deposits as they overlap the Mississippian rocks

runs northwestward just north of the Pope-Massac County line for 12 miles or more and then continues almost coincident with this county line until within a mile or two of the chain of swamps in northern Massac County. It then curves southwestward and westward parallel and 1 to 2 miles south of this chain of swamps and the westward continuation of the same low valley, once occupied by the Ohio, but now by the Cache, until it crosses the Cache at Ullin. It continues its westward course 4 or 5 miles west of Ullin, and then curves southwestward until near the northern end of Horseshoe Lake. Thence it turns westward and reaches Mississippi River at Santa Fe. The area thus included is about 480 square miles.

Topography.—The region may be divided topographically into three parts. The first is the present low flood plain of Mississippi, Ohio, and Cache rivers. The second is a higher, older flood plain corresponding to the terrace level found south of the Ohio in Kentucky. In some places the edge of this old plain is well marked, while in others it seems to rise irregularly from the lower bottom. It is most prominently developed on the Ohio in Massac County above Metropolis. The third part is the rolling to hilly upland surface, the average elevation of which is probably near 400 feet.

Geology.—The formations found within the area are the Ripley, Porters Creek, Lagrange, Lafayette, loess, and alluvium. In addition, the underlying Paleozoic rock that forms the floor of the embayment region outcrops in a few places near the edge of the area and in Ohio River at Grand Chain, where it is evidently faulted. It is also reached in the few places where deep wells have been sunk.

The surficial covering so thoroughly conceals the embayment formations that it is impossible to give with any great accuracy their areal extent without much detailed work, and even then extensive boring would very probably be necessary to accurately delimit them. It may be said, however, that the Ripley underlies the loess and Lafayette probably over a small area in the south end of Pope County and over all of Massac County included within the embayment region. Along its northern edge it is rather thin, and ordinary wells occasionally go through it and enter the Paleozoic rock, here usually a limestone. The Ripley consists of interbedded clays and sands. The clays are either light colored and plastic, in which case they may be mined for pottery use, or dark blue or brown, from disseminated organic matter or lignite. Occasionally one of these dark-blue clays struck in ordinary wells is fetid, probably from hydrogen sulphide. The sands are in most cases fine grained. Here and there a coarse bed is struck, and at the base of the formation there is reported to be a gravel and cobble bed forming a basal conglomerate. This formation is exposed in various places between Grand Chain Landing and New Grand Chain and between Metropolis and

New Columbia, and is very similar lithologically to the Lagrange formation as typically developed in Tennessee. In the clay pits at Grand Chain Landing the clays contain leaf impressions. The Ripley probably forms most or all of the exposures of sand and clay to be seen along the Cache River bluffs below Ullin.

The Porters Creek is exposed at the surface only in the bluffs near North Caledonia, and even there the exposure contains so much sand and sandy clay that it could not be surely identified as Porters Creek were it not for the greensand present. As already stated greensand indicating marine conditions is found in Tennessee and Kentucky to be characteristic of the Porters Creek, but is entirely absent in the Ripley below and in the Lagrange above, both of which are of nonmarine origin. The Porters Creek is struck in the deep well at Mound City at a depth of 180 feet and is 100 feet thick. At Cairo it is reached at a depth of 375 feet and is 124 feet thick. In each case only 25 feet of sand representing the Ripley, if the writer's interpretation of the section is correct, were found under the Porters Creek. The areal extent of the formation west of the North Caledonia exposure is not known. It may have a narrow surface outcrop or may be entirely concealed by the overlap of the Lagrange.

The Lagrange also is poorly exposed in Illinois, but from exposures and well sections in Kentucky a short distance south of Cairo it seems practically certain that its base is reached in the Cairo wells at a depth of 375 feet and at Mound City at a depth of 180 feet. Since it is not much different lithologically from the Ripley, both being nonmarine, more or less lignitic sands and clays, it is possible that at least a portion of the sand and clay found north of Grand Chain and Metropolis may really belong to the Lagrange, having overlapped the Porters Creek outcrop. While field exposures might fail to settle the question thus raised, it should be capable of easy solution from the paleobotanical evidence in the shape of leaf impressions which the clays in that border region would furnish. Unfortunately no such study has yet been made of these deposits.

The Lafayette contains its customary quota of chert gravel, and a larger proportion of it than usual is cemented by limonite into an ironstone conglomerate. It is found on the uplands wherever stream cuttings or railway excavations have gone below the loess and is seen along the bluffs of the Ohio in a few places. At Metropolis and just above, at old Fort Massac, a well-cemented ironstone conglomerate is exposed at or near water level and extends below it. This material possesses apparently all the characters of the Lafayette and may be of that age, but the ease with which gravels of even very recent age may become cemented into a firm ironstone that looks very much like typical Lafayette gravel was forcibly impressed on the writer some time since during a trip down Tennessee

River, and so he prefers to regard the age of these conglomerates in the Ohio, while probably Lafayette, as not clearly proved.

On the uplands the loess mantles everything in Pulaski County, and it is also found in numerous places in the western part of Massac County from Metropolis northward, though much thinner than in Pulaski County.

The alluvium occurs in the low plain of Mississippi, Ohio, and Cache rivers.

Water resources.—Springs and small streams are not very abundant in the region, and ponds are commonly in use for stock. The domestic supply is derived from wells and cisterns. Water from wells on the uplands varies much in quality and in depth. It is hard or soft, according to the presence or absence of the loess. In some places it is inconveniently deep and in a few instances it is reported as foul smelling. In many cases, however, good water is obtained in open wells and a large number of such wells are in use. Some farmers have wells, cisterns, and ponds. In the alluvial region the shallow water is hard, and at Cairo and Mound City deep wells have been put down that furnish an abundance of water suitable for most purposes.

At America, Pulaski County, wells of moderate depth and cisterns are used. Two miles to the west, on what is probably an extension of the terrace plain, wells run 25 to 30 feet deep and give hard water. The section is entirely through clay, and it seems that deeper wells fail to find Lafayette gravel, showing that probably it had been cut out before the clay was deposited. The clay is very likely the equivalent of the loess on the hills farther north. These hills rise 40 to 60 feet, and in them wells strike hard water at depths of 30 to 40 feet in the Lafayette gravel beneath the loess. Some wells go through this gravel and get water at greater depth in what is probably Ripley, though it may be overlapping Lagrange. The quality of the water would be about the same in either case.

One and three-fourths miles south of Belknap, Johnson County, on the bayou, a driven well entered, at a depth of 12 feet, a sand that was somewhat quick and contained lignitic streaks and gravel layers at intervals. It was sunk to 116 feet, when the pipe proved too weak to drive farther and the well was abandoned. Water rises 112 feet in it. This shows a considerable depth of soft material, probably largely or entirely alluvial, in the abandoned channel of the Ohio at this locality.

At Cairo, Alexandria County, elevation of extreme low water 267 feet, of high water 321 feet, and of union depot 313 feet, water is struck in sand and gravel deposits underneath the surface clay at a depth of about 50 feet. It is hard and otherwise objectionable from a sanitary point of view. Cisterns were formerly used, but

difficulty was experienced in preventing them from cracking and letting in seepage water. The city water supply is obtained from Ohio River. It is pumped at the rate of about 2,000,000 gallons per day into a standpipe 160 feet high. The water contains some lime and scales somewhat. One firm heats water for boiler use to between 186° and 206° F., and thus precipitates most of the calcium carbonate.

In and near Cairo several deep wells have been sunk. The location and logs of several of them are as follows:

The first deep boring is at the power station of the Cairo Electric Light and Power Company, on lot 29, city block 26, and was drilled in 1896–97 to a depth of 1,040 feet. The diameter is 10 inches at the top and decreases to 6½ inches at the bottom. The log is as follows:

Log of well of Cairo Electric Light and Power Company, Cairo, Ill.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	4.5	4.5
Sandy blue clay	50.5	55
Sand and gravel, similar to river deposit	60	115
Sand with kaolin partings	15	130
Kaolin	4	134
Sand with a few thin layers of kaolin and traces of shale and lignite	240	374
Shale or marl, slate colored	124	498
Very soft sand	20	518
Partings of shale and lignite	5	523
Chert or "Elco" gravel	177	700
Chert pebbles	5	705
Hard, reddish calcareous sandstone; no water in it	335	1,040

From the sand at 498–518 feet water rose to the surface and flowed about a gallon a minute. The following sanitary analysis of this water was made at the University of Illinois by Prof. A. W. Palmer:

Analysis of water obtained between 498 and 518 feet from well of Cairo Electric Light and Power Company, Cairo, Ill.

	Parts per million.
Nitrogen as free ammonia	0.35
Nitrogen as albuminoid ammonia	.022
Nitrogen as nitrites	.009
Nitrogen as nitrates	.204
Chlorine as chlorides	83
Oxygen consumed	3.4
Total solids by evaporation	365
Fixed residue	348
Volatile matter (loss on ignition)	17.1

Comments of analyst: "Too much time—ten days—had elapsed between collection and analysis to be sure of sanitary condition, though it is probably satisfactory. The mineral matter consists mainly of carbonate of lime, with some sodium chloride and very

little sulphate. Not excessively hard. Not likely to form a hard scale in boilers."

Professor Palmer also analyzed the water from the 705-foot level, with the following results:

Analysis of water from depth of 705 feet in well of Cairo Electric Light and Power Company, Cairo, Ill.

[Parts per million.]

	1.	2.
Nitrogen as free ammonia	0.36	0.36
Nitrogen as albuminoid ammonia	.016	.02
Nitrogen as nitrites	None.	None.
Nitrogen as nitrates	.06	.06
Chlorine as chlorides	110	110
Oxygen consumed	1.4	1.2
Total solids by evaporation	356	353
Fixed residue	346	339
Volatile matter (loss on ignition)	10	14
Hardness	115	....

Comments of analyst: "Of exceptional purity and perfectly safe and wholesome for drinking. Hardness is quite moderate." The two samples were taken at the same time.

The Halliday Hotel well, on lot 24, hotel addition to city of Cairo, has practically the same log as the one given above. The boring went to 824 feet, but there was no increase of water below the 700-foot level. It was drilled in 1897; diameter at the top 8 inches, at the bottom 4½ inches; temperature 62° F.; head 12 feet above the surface.

A well on the W. P. Halliday estate, near the mouth of Cache River, in about the center of the NE. ¼ sec. 2, T. 17 S., R. 1 W., in Alexander County, had the following log:

Log of Halliday well in the NE. ¼ sec. 2, T. 17 S., R. 1 W., Illinois.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and blue clay (buckshot)	40	40
Sand and gravel; drift with kaolin partings	104	144
Brown shale or marl	112	256
Gray sand	54	310
Chert, fractured—"flint rock"	72	382
Dark-brown sand	10	392
Chert, fractured—"flint rock"	34	426
White sand	42	468
Flint rock with slight fractures	62	730
Flint pebbles	7	737
Flint rock	69	806

From the last 7 feet water with a head of 12 feet flows at an estimated rate of half a million gallons a day. There was no increase in water below 735 feet. Drilled in 1898; temperature 62° F.

Another well at E. W. Halliday's residence on lot 16, block 70, between ninth and tenth and Walnut and Cedar streets, in Cairo, had the following log:

Log of well at residence of E. W. Halliday, lot 16, block 70, Cairo, Ill.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and friable blue clay (loess or terrace)	50	50
White sand with thin partings of kaolin (Lagrange)	325	375
Gray shale or marl (Porters Creek)	130	505
Fine, closely compacted white sand (Ripley)	24	529
Flint rock, but slight fractures (Paleozoic)	220	749
Flint pebbles	4	753
Hard calcareous sandstone	58	811

From the 753-foot level there is a flow of 60 gallons per minute, with a head of 12 feet above the surface. The temperature is 62° F. Four hundred gallons per minute may be pumped.

There are other similar wells at several manufacturing establishments in Cairo and the records run much the same. The temperature seems to be 62° F. in each case and the static head is the same. The material described as flint is a very light colored chert of Mississippian age that is exposed in a 150 or 200 foot face at a quarry between Tamms and Elco, from which it is extensively shipped for railroad ballast and road metal. In this locality it is highly fractured, so that it is virtually of macadam size without crushing. As struck in wells it is in some places massive and solid, while in others it is seamed and broken, and is then called gravel by the drillers, though in neither wells nor in the Elco gravel quarry is the material waterworn or rounded, being simply mechanically disintegrated chert still in place.

Grand Chain station, Pulaski County, is on the upland. The surface is covered with loess to a depth of 10 to 40 feet. In a few places it is cut through and the Lafayette gravel beneath is revealed. Many people use cisterns. Water is struck at depths ranging from 20 feet in low places to 85 feet on higher levels. Much of it is hard. Ponds are generally used for stock.

At Metropolis, Massac County, wells in town are from 30 to 50 feet, and end in what seems to be Lafayette gravel, as it is exposed near old Fort Massac at water level in ledges that dip gently under water and reappear a mile up the river. North of town wells average 50 to 60 feet in depth, and get water from the Ripley sand a short distance beneath the Lafayette gravel. In some places wells have been dug 150 feet without getting water. As a rule the water is soft, especially in the deeper wells. Cisterns are easily excavated in the soft loess that forms the surface and many are used.

Northeast and east of Metropolis water is found at depths of 60 to 125 feet in the Ripley sands, where they are not too close grained to furnish an adequate supply, as is often the case. Many cisterns are in use in this section of the county.

At Mound City, Pulaski County, there is an 8-inch well that flows with a 6-foot head. No analysis of the water could be obtained. It is fairly good for boilers and is used for ice making and general town supply. The log is as follows:

Log of well at Mound City, Ill.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface clay	20	20
Gravel and sand (Lagrange)	160	180
Blue shale (Porters Creek)	100	280
Dark sand (Ripley)	25	305
"Elco" gravel (Paleozoic)	300	605
Limestone	45	650

Round Knob, Massac County, is just south of the swamps that mark the old course of the Ohio westward across the northern part of the county. Hard Paleozoic rock is struck at depths of 20 to 30 feet and so very few wells have been put down. Cisterns may be easily constructed in the loess, sand, and gravel that cover the old hard rocks and they are used almost exclusively. In the swamps to the north water is everywhere near the surface and is readily obtained by driving a few feet of pipe and attaching a small suction or pitcher pump, as it is usually called. Needless to say the quality of this surface swamp water is not the best.

At Tamms, Alexander County, on a part of the old river-terrace plain, water is obtained from driven wells of 18 to 25 feet depth in river gravel and alluvium. Some wells give hard water, others soft. Cisterns are largely used.

PROPERTIES OF THE WATER.

As might be expected the underground waters of the region discussed in this paper vary much in quality, but the variations are caused chiefly by differences in the amounts of a few substances that are ordinarily found present.

The most common type of water may be described as a pure water, or one practically free from mineral ingredients. Many of the springs and shallow wells and a number of the deep wells furnish water of this character. This is especially true of springs and wells located in the sandy formations such as the Eutaw, Ripley, Lagrange, and, in a restricted sense because of its thinness, the Lafayette. The purer sands of these formations contain very little that is soluble in the water that percolates through them and hence it contains little or no dissolved mineral matter.

When the sands are not pure but contain, as they do in certain places, vegetable matter, usually in the form of lignite, along with various chemical compounds that have resulted from its decompo-

sition, the water is apt to dissolve more or less of these substances and acquires thereby a mineral character.

The above-mentioned formations, with the exception of the Lafayette, contain beds of clay here and there that are generally lignitic and as a result contain more or less iron pyrite. Water derived from these clay beds is always more or less mineralized, but in many cases is perfectly usable for most purposes. Such mineral waters are described along with others on page 120. These clays exist either as strata of considerable areal extent or as local lenses embedded in the sands, but though they may be silty and somewhat porous there seems to be as a rule very little circulation of water between them and the surrounding sand. A well ending in the silty clay may derive a scant or moderate supply of water from it, and another near by, ending just above or just below it, may furnish a pure water of very different character. This is especially true of local lenses of clay or silt that occur in the Lagrange. They probably represent either old stream channels abandoned and silted up or similarly filled old long-shore lagoons behind sand bars of the contemporary estuary in which the sands were then being deposited. Deep waters are more apt to contain mineral matter than shallow waters in the same kind of material, because of the many chances for deep waters, in their long underground course form their entrance into the beds to their exit in wells, to come into contact with soluble substances, and this tendency is further increased by the greater solvent powers they possess by being under pressure during their slow underground course. In view of this fact it is surprising that so many of the deep waters are so pure.

The mineral waters of the region come either from the clays contained in the Eutaw, Ripley, or Lagrange formations or from the Selma, Porters Creek, loess, or alluvium. Local clay beds may possibly be struck in the Eutaw, Ripley, and Lagrange at almost any place, so that no geographic bounds for such cases can be stated. Wherever struck, however, good water may usually be gotten by going somewhat deeper and entering an underlying sand.

The areas of Selma, Porters Creek, loess, and alluvium may be seen from the geologic map (Pl. I, p. 26). In the Selma clay area the water is usually hard because of the calcium carbonate it contains, while in the Porters Creek area it is hard usually from the same cause and may contain in addition sulphates of iron and alumina, which make it astringent or like alum to the taste. In some places the Porters Creek water contains so much sulphureted hydrogen that both man and beast refuse to touch it. In the loess area the water is hard because of calcium carbonate dissolved from the loess. In the alluvial region the water usually contains iron carbonate or sulphate and very often calcium and magnesium carbonate and sulphate in addition.

The mineral salts usually found in the waters of the region, then, are calcium and magnesium carbonate and sulphate, iron carbonate, and occasionally iron sulphate. Carbonic acid gas is present in the carbonate waters to hold the lime, magnesia, and iron oxide in solution, and sulphureted hydrogen is occasionally found. These and and other compounds appear in the chemical and sanitary analysis given in the preceding pages. They will each be discussed briefly here and the way they affect the quality of the water will be indicated.

The calcium and magnesium carbonate and sulphate render the water hard. This hardness may be removed by boiling or by heating almost to the boiling point when it is caused by the carbonates, and such water is known as temporarily hard. If, however, the hardness is caused by the sulphates it can not be so readily overcome and the water is then said to be permanently hard.

When soap is added to a hard water, chemical combination occurs between the soap and the carbonates and sulphates and no soap is available for making a lather to aid in washing until all of these salts have thus entered into combination. In this way much soap is wasted and the insoluble compounds formed make a sticky, gummy precipitate that is disagreeable and highly objectionable. Hard water is therefore undesirable for washing and laundry purposes.

If the hardness is temporary—that is, due to carbonates—it may be removed by a preliminary boiling of the water, when the free carbonic acid which holds the carbonate in solution is driven off and the carbonate is precipitated. If the hardness is permanent, or due to sulphates, it can be removed only with considerable more difficulty by processes which are described in the discussion of boiler waters (p. 157). Most of the hard waters of the region are "temporarily hard."

In cooking, hard water deposits incrustations on the inside of vessels in which it is boiled and also deposits lime salts on the vegetables or meats and tends to darken vegetables cooked in it. For drinking, however, it is probably not objectionable from a sanitary point of view, though it may impart a taste to the water not entirely pleasant, and is supposed by many to be harmful in rheumatic and gouty disorders. In certain diseases of the bowels, kidneys, and bladder the carbonate of calcium is probably beneficial and the carbonate of magnesium is even more valuable.

There is comparatively little definite information as to the effect of hard water when used for stock. In some places a good proportion of the diseases of horses is attributed to their drinking hard water.

Iron carbonate when held in solution in water by an excess of carbonic acid is precipitated when the water reaches the surface and is allowed to stand for some hours, thus permitting the escape

of the carbonic acid. The precipitated iron carbonate decomposes and an iron oxide is formed, which may be seen as a red or yellow slimy incrustation in the vessel holding the water or along its course from a spring. Such water is at first clear and sparkling. On standing, it becomes more or less opalescent or milky while the precipitation is going on and when this is completed it is once more clear, but is no longer chalybeate.

Aside from the lime and magnesia salts already mentioned, iron carbonate is the most widely distributed of the minerals in the waters of the region. Nearly all the "mineral springs" of the region are chalybeate. For cooking purposes such water is objectionable because of the discoloration caused by the precipitated iron. It is even more objectionable for washing white clothes, as it stains them yellow or brown.

Iron is an essential ingredient of the red corpuscles of the blood and is also found in various other portions of the body. Chalybeate waters are valuable for drinking in cases of anemia and generally in impoverished conditions of the blood arising from any cause.

Sulphate of iron is found in some of the waters, especially in those of the Porters Creek area. Such water is astringent and tonic, but is not so palatable nor so generally valuable as a remedial agent as that containing carbonate of iron.

In the carbonated waters free carbonic-acid gas enables the water to hold in solution such carbonates as may be present. This gas imparts to the water an attractive sparkle and is an aid in cases of indigestion and stomach disorders. Sulphureted hydrogen is present in some springs and wells and may be instantly detected by the odor as of rotten eggs which characterizes it. Such water is considered of value in certain kidney and bowel troubles and in rheumatism, gout, and skin diseases.

In sanitary analyses judgment as to the healthfulness of any given water must be based very largely on a knowledge of the local conditions or surroundings, and the analytical findings should always be interpreted by such knowledge.

USES OF THE WATER.

The principal uses of water in this region are for household and laundry purposes, stock watering, and steam boilers, but it is also used to a greater or less extent for soap making, wool washing, dyeing, brewing, and distilling. In the section on properties of the water sufficient reference was made to the qualities necessary for household, laundry, and stock use. The qualities of water which affect its use for the remaining purposes mentioned above will be briefly described here.

The most important industrial use of water in the region is for

steam boilers. Numerous steam sawmills, corn and flouring mills, and cotton gins are scattered over the region, while in the towns and cities steam is used for a great variety of power purposes. The railways use large quantities in their locomotives and at many places have sunk their own deep wells.

Where the boiler water is soft, no difficulty arises from its use, but where hard a deposit known as scale forms in the boiler. The scale formed by water containing calcium or magnesium carbonate is deposited in the bottom of the boiler, usually as a loose, soft slush, that is easily removed by blowing off the boilers. If the water is permanently hard, however, the scale formed by the calcium and magnesium sulphates is deposited on the tubes and bottom of the boiler as a hard coating that is difficult to remove, and because it is such a poor conductor of heat causes a much larger fuel consumption for the same steam production. It is calculated that scale one-fourth inch thick requires 50 per cent increase in fuel and scale one-half inch thick 150 per cent increase.

To obviate the difficulties arising from scale, hard water may be softened by treatment before or after being introduced into the boiler. If temporarily hard water is raised to the boiling point before being used for feed water, the carbonates are deposited. This practice is followed at a number of steam plants in the region. There is some loss of heat by radiation in the softening tanks, but the net cost is low, as the softened water enters the boiler at almost the boiling point. Permanently hard water does not deposit its sulphates at boiling temperature, but must be heated in a closed vessel to a temperature of 150° C. or over. and even then the precipitation is not complete. Such water may be softened more conveniently by adding sodium carbonate, when a chemical interchange takes place, and sodium sulphate and calcium carbonate form and are precipitated as a soft, incoherent deposit that may be easily removed.

Many steam plants in the region use boiler compounds, certain quantities of which are introduced into the boiler at stated intervals. Such compounds when intelligently and carefully prepared are efficient and satisfactory, though it is probable that in most cases they cost entirely too much. It may be said that 3 cents per thousand gallons is a fair cost for softening and that any excess above this sum is so much money wasted. Aside from the question of cost, however, an honestly prepared boiler compound has many advantages for the small plant, where often the boiler is cared for by a man without the technical knowledge necessary for applying an intelligent treatment to the water.

Many substances are recommended for the treatment of water in the boiler. Some act chemically, while others are mechanical and designed to entangle the scale or mix with it and prevent its getting

hard or adhering firmly. Some of these are good, others may do neither harm nor good, while still others at the temperature and pressure of a working boiler are corrosive and injurious. They include such substances as powdered glass, tan bark, coal dust, molasses, sawdust, chips of wood, burnt sugar, ground coffee, logwood, soda ash, caustic soda, table salt, and many others. Any treatment should be applied only with a full knowledge of the composition of the water.

In soap making soft water is highly desirable, because calcium and magnesium salts cause a loss of lye by their union with it to form insoluble compounds that are useless for cleansing purposes.

In some cases farmers in the region wash their own wool clip, and there are one or two woolen factories that also wash wool. The water for such use should be soft. Hard water makes the fiber less pliable and in the finishing stages of the washing a deposit of lime salts is formed that clings to the wool and interferes with dyeing.

In dyeing as pure a water as possible should be used. If it contains organic matter, putrefaction of the dye extracts used may result. Lime is objectionable in mordanting and aniline dyes dissolve poorly in water containing it. Iron is also harmful in dyeing with certain colors and is prohibitive of bleaching.

The quality of the water used in brewing has a very important influence on the color, taste, and other qualities of the beer produced. The water so used should be a good drinking water and free from organic matter. Ammonia, nitrates, and nitrites are objectionable. Calcium sulphate improves the quality of the product, and if deficient is added. Sodium chloride in small quantities is not objectionable, but in larger quantities prevents the germination of the malt. While a little iron may be harmless, it makes the product darker and in larger quantities interferes with malting and may produce an objectionable odor. Calcium and magnesium carbonates should be present in moderate quantities, especially if calcium sulphate is deficient. They tend to give the product a lighter color and to improve its taste and keeping qualities. Organic matter is harmful since it causes putrefactive fermentation in the malt. Iron compounds retard germination. Calcium chloride checks the development of the yeast in the fermentation of beer, while calcium sulphate promotes it. Much the same is true of the qualities desirable in distilling.

STATIC LEVEL OF UNDERGROUND WATER.

The elevation to which underground water rises in a number of the more important places in the region has been ascertained with as much accuracy as possible. In a few cases where there was an

uncertainty involving only a few feet one way or the other, this is indicated by the ± sign. Where data given are suspected of being entirely wrong, the figure is followed by an interrogation mark.

As shown on the sketch map (fig. 13), these elevations are fairly

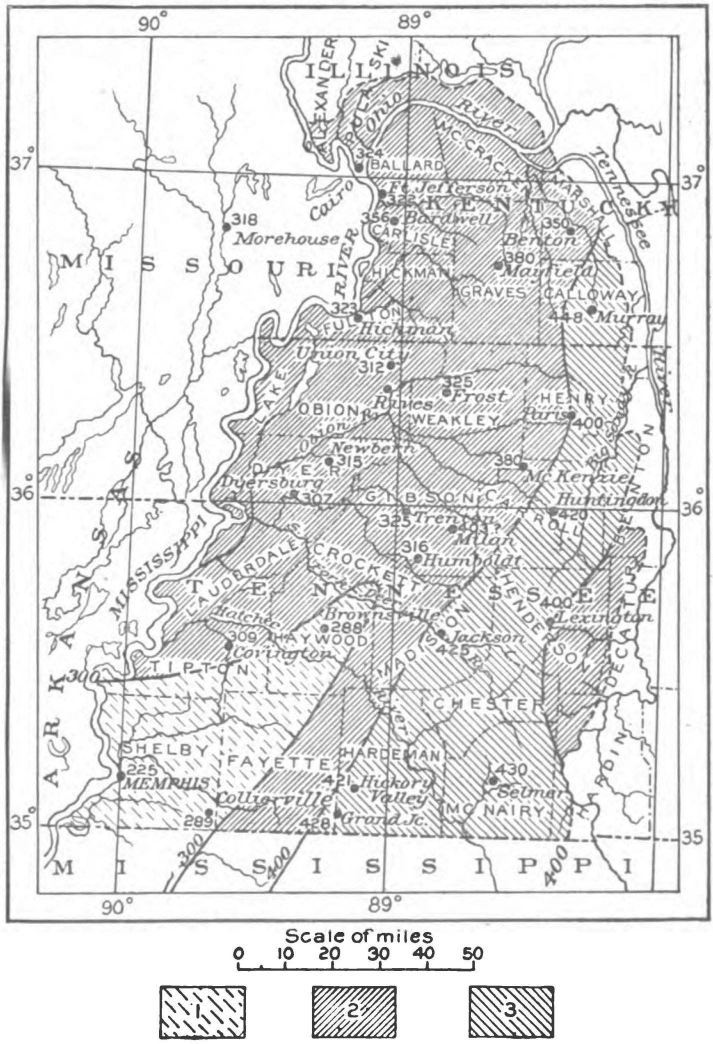

FIG. 13.—Sketch map showing hydrostatic levels. 1, Water rises between 200 and 300 feet above sea level; 2, between 300 and 400 feet; 3, between 400 and 500 feet.

well distributed over the area and vary in a rational way, in view of the facts that the outcrop of the porous beds in the embayment area across Tennessee and Kentucky is to the east and that water flowing through these beds encounters friction enough to cause it to rise to successively less and less height as it goes westward. Water

also enters at the outcrop across the north end of the area in Illinois and flows southward with a similarly decreased gradient. By reference to the map an approximation may be had of the height to which underground water would rise at almost any place in the region. The following list gives the elevation above sea level to which deep underground water rises at the places indicated:

Elevation to which underground water rises in embayment area of Tennessee, Kentucky, and Illinois.

	Feet.		Feet.
Bardwell, Ky	356	McKenzie, Tenn	380
Benton, Ky	350	Martin, Tenn	325
Brownsville, Tenn	288	Mayfield, Ky	380±
Cairo, Ill	324	Memphis, Tenn	225
Collierville, Tenn	289	Milan, Tenn	403?
Covington, Tenn	309	Morehouse, Mo	318
Dyersburg, Tenn	307±	Murray, Ky	448
Grand Junction, Tenn	428	Newbern, Tenn	315
Hickman, Ky	323	Paris, Tenn	400
Hickory Valley, Tenn	421	Rives, Tenn	300
Humboldt, Tenn	316	Selmer, Tenn	430
Huntington, Tenn	420	Trenton, Tenn	325±
Jackson, Tenn	435±	Union City, Tenn	312
Lexington, Tenn	400	Wickliffe, Ky	322±

METHODS AND COST OF WELL DRILLING.

In olden times open dug wells were the only kind used, and in localities where underground waters are near the surface they are still common. In most cases they are 3 or 4 feet in diameter. Where the material is very firm they are either not cased or the casing is set in only the lower part. Where the material is soft a casing, usually of wood and square, is used for the whole depth. Occasionally such wells are walled with brick. Where 20 to 40 feet deep they cost on the average from 40 to 50 cents per foot to dig if in soft sand or loess. If the material is clay and harder the cost is somewhat more.

The bored well was next introduced in the region. The first one was put down toward the middle of the nineteenth century and they soon became common in the Selma clay and other areas where it was necessary to go to considerable depths, such as 200 feet or more. These wells were usually 10 or 12 inches in diameter and in firm clay were left uncurbed below the first 10 or 20 feet. In softer materials, where curbing was necessary, a square or octagonal curbing of 2-inch plank was pushed down after the auger, which was essentially like a wood auger. In case a consolidated layer was struck it was broken to pieces, usually by a crowbar or other heavy iron let drop drill fashion upon it. Long cylindrical buckets with

valves in the bottom are used for drawing the water. In many places such wells are put down to-day and prove very satisfactory. They cost 15 to 30 cents per foot, according to kind of material and depth.

Driven wells have come into use within comparatively recent years. Where the depth to water is known to be slight a 2 or 3 inch piece of iron pipe, usually galvanized, is shod with a short strainer, or perforated section, pointed sharp at the end, and driven by force into the ground, and a small suction or pitcher pump attached to the upper end. Such a well has the advantage of having a tight joint between the earth around and the outside of the pipe, so that surface water and contamination can not directly enter the well by trickling down the sides of it. Such a well 20 to 40 feet deep will cost complete considerably less than a dollar per foot. Sometimes such wells are driven deeper, but a depth is soon reached beyond which it is not practicable to drive the pipe, as it telescopes.

Where greater depth is necessary than can readily be obtained by driving, the pipe is "pumped down," as it is called. An outer pipe is sunk into the ground and within it is sunk another which is shod on its lower end with a small chisel or cutting edge to loosen up the material and which has a current of water forced down through it to wash to the surface the earth loosened by the bit. Such wells are in many cases 2 inches in diameter and 100 to 200 feet or more in depth. A well of this size usually furnishes an adequate supply for all household purposes. At mills of any kind wells 3 to 4 inches in diameter are often used. For a town or other large supply the diameter is 6, 8, 10, or 12 inches and the inner pipe is kept turning; this mode of drilling is called the hydraulic rotary process. In work in quicksands the counter pressure of the column of water forced down from the surface is often the only thing that prevents the sand from rushing up inside the outer pipe and settling around the tools so that it would be impossible either to sink farther or pull back the pipe or the tools. Such work requires much experience and care, and if quicksands are encountered the tools are kept going day and night from the time the well is started until it is finished, to prevent the loss of the well and tools.

If hard beds are encountered, an ordinary hard-rock deep-well drill must be used, and the hole may have to be reamed out afterwards in order to drive the casing lower. In some cases where hard rock, such as the Paleozoic floor beneath the embayment deposits was struck, a diamond drill has been used to deepen the well. At Cairo, Ill., and elsewhere in that vicinity, however, such attempts were unsuccessful because of the hard, sharp-edged chert, or "Elco" gravel, encountered. This chert soon tore the diamonds from their setting or cut to pieces the soft iron cuff that held them and caused their

loss. The ordinary chisel-shaped deep-well drill was substituted and worked without trouble.

Where such wells are drilled the outfit of the driller must be extensive and must include a standard-sized deep-well rig or derrick and equipment for hard rock, sand, clay, and quicksand. It is work, too, in which experience and good judgment are necessary in deciding where to place the strainer or finish the well in order to get a good supply of water, free from milkiness or clay, and from sand that will slip through the strainer slots to cut them out, clog up the well, or cut out valve packing and piston chambers. Drilling soft deposits, such as characterize this region, is an art in itself and requires experience that can be obtained only in such a region. No amount of drilling in hard rocks will prepare a driller for successful work in soft materials.

The cost of drilling wells of this type varies somewhat, but for wells 150 to 200 feet deep the cost per foot runs about as follows: Two-inch, $1; 3-inch, $1.50; 4-inch, $2; 6-inch, $3.50; including casing and a hand pump for the smaller wells. For large, deep wells, where a more elaborate outfit is necessary, the cost is considerably more, and for 10-inch wells 600 to 1,000 feet deep or over may run $7 to $9 per foot. The Memphis wells cost complete with the best of materials and double or triple casing and tunnel connections about $5,000 each, while private wells there ranging from 400 to 600 feet deep can be bored for about $8 per foot. There is one record of a well in another part of the region drilled partly 8-inch and partly 6-inch and about 600 feet deep for $1,800, but this is exceptionally low and probably the figures given were not meant to include the cost of the casing.

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BIBLIOGRAPHY.

The following list does not pretend to be exhaustive, but gives what are believed to be the references most important for an understanding of the geology and hydrography of the region here described:

CHAMBERLIN, T. C.

1. Some additional evidence bearing on the interval between the Glacial epochs: Bull. Geol. Soc. America, vol. 1, 1890, pp. 469-474, 475-476, 478-479.
2. The attitude of the eastern and central portions of the United States during the Glacial period: Am. Geologist, vol. 8, 1891, pp. 233, 267-275.

CHAMBERLIN, T. C., and SALISBURY, R. D.

1. On the relationship of the Pleistocene to the pre-Pleistocene formations of the Mississippi basin, south of the limits of glaciation: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 359-377; also in part in The Geology of Crowleys Ridge, by R. E. Cain: Rept. Arkansas Geol. Survey for 1899, vol. 2, pp. 224-228.

DABNEY, T. G.

1. Geology of the Mississippi embayment: Jour. Memphis Eng. Soc., vol. 4, no. 3, 1905, pp. 11-26.

GILMORE, Q. A. (president Miss. River Comm.).

1. Report of the Mississippi River Commission for 1881: Senate Ex. Doc. No. 10, 47th Cong., 1st sess., 1882. Contains levels, high and low water profiles, and location, logs, and plotted sections of many borings by army engineers between Cairo and Memphis.

GLENN, L. C.

1. [Notes on the wells, springs, and general water resources of] Tennessee: Water-Sup. and Irr. Paper No. 102, U. S. Geol. Survey, 1904, pp. 358-367.
2. [Notes on the well, springs, and general water resources of] Kentucky: Water-Sup. and Irr. Paper No. 102, U. S. Geol. Survey, 1904, pp. 369-372.
3. [Notes on the underground water of] Tennessee and Kentucky: Water-Sup. and Irr. Paper No. 114, U. S. Geol. Survey, 1905, pp. 198-208.
4. Fossiliferous sandstone dikes in the Eocene of Tennessee and Kentucky, abstract in Science, new ser., vol. 19, 1904, p. 522.

HAMPTON, S. W. (chairman of water commission).

1. Report on a public water supply for the city of Memphis. 60 pp., with maps. Memphis, 1887.

HARRIS, G. D.

1. The Tertiary geology of southern Arkansas: Ann. Rept. Arkansas Geol. Survey for 1892, vol. 2, pp. 1-207. Contains geologic maps.
2. The Midway stage: Bull. Am. Paleontology, vol. 1, No. 4, 1896, 125 pp., 15 pls.
3. The Lignitic stage: Bull. Am. Paleontology, vol. 2, No. 9, 1897, pp. 3-102, 15 pls.

HIDER, ARTHUR; OMBERG, J. A., jr.; and BELL, A. T.

1. Engineer's report on the waterworks system of Memphis, Tenn. 46 pp., maps and plates. [Memphis, 1902.]

HILGARD, E. W.

1. Report on the geology and agriculture of Mississippi. xiii, 391 pp., plate, map. Jackson, 1860.
2. On the Quaternary formations of the State of Mississippi: Am. Jour. Sci., 2d ser., vol. 41, 1866, pp. 311-325.
3. Remarks on the drift of the Western and Southern States and its relation to the glacier and iceberg theories: Am. Jour. Sci., 2d ser. ,vol. 42, 1866, pp. 342-347.
4. The loess of the Mississippi Valley and the æolian hypothesis: Am. Jour. Sci., 3d ser., vol. 18, 1879, pp. 106-112.
5. General features of the alluvial plain of the Mississippi River below the mouth of the Ohio: Tenth Census U. S., vol. 5, Report on cotton production in the United States, 1884, p. 73-76 (bottom pagination).
6. Orange sand, Lagrange, and Appomattox: Am. Geologist, vol. 8, 1891, pp. 129-131. With an appended note of approval and concurrence by J. M. Safford.
7. [Mode of deposition of the Lafayette formation in the Mississippi Valley]: Am. Geologist, vol. 8, 1891, p. 235. Discussion of paper by W J McGee, "Neocene and Pleistocene continent movements," read to Am. Assoc. Adv. Sci., 1891.
8. The age and origin of the Lafayette formation: Am. Jour. Sci., 3d ser., vol. 43, 1892, pp. 389-402.

KILLEBREW, J. B., and SAFFORD, J. M.

1. Introduction to the resources of Tennessee. viii, 1, 193, xi pp., 7 maps. Nashville, 1874.

LITTLE, GEORGE.

1. Report on the blue clay of the Mississippi River: Rept. U. S. Coast and Geodetic Survey for 1880, 1882, Appendix 12, pp. 145-171, pl. 48; Rept. Chief of Engineers U. S. Army for 1883, part 3, pp. 2315-2339; also reprint.

LOUGHRIDGE, R. H.

1. Report on the geological and economic features of the Jackson Purchase region, embracing the counties of Ballard, Calloway, Fulton, Graves, Hickman, McCracken, and Marshall. Geol. Survey Kentucky, 1888. 357 pp., plates, 3 maps in pocket.

LUNDIE, JOHN (consulting engineer).

1. Report on the waterworks system of Memphis, Tenn. 46 pp., maps and plates. Memphis [1898].

MARBUT, C. F.

1. The evolution of the northern part of the lowlands of southeastern Missouri: Univ. Missouri. Studies, vol. 1, No. 3. viii, 63 pp., plates, 4 maps. 1902.

MCGEE, W J.

1. Three formations of the middle Atlantic slope: Am. Jour. Sci., 3d ser., vol. 35, 1888, pp. 120-143, Pl. II; pp. 328-330, 367-388, 448-466, Pls. VI, VII.
2. The southern extension of the Appomattox formation: Am. Jour. Sci., 3d ser., vol. 40, 1890, pp. 15-41.
3. [Remarks on the formations comprised under the term "Orange sand," and on the relations of certain loams and gravels in the vicinity of Vicksburg and Grand Gulf]: Bull. Geol. Soc. America, vol. 1, 1890, pp. 474-475. Discusses paper by T. C. Chamberlin on "Some additional evidence bearing on the interval between the Glacial epochs."
4. Neocene and Pleistocene continent movements: Abstract in Am. Geologist, vol. 8, 1891, pp. 234-235; also in Proc. Am. Assoc. Adv. Sci., vol. 40, 1891, pp. 253-254.
5. The Columbia formation in the Mississippi embayment: Abstract in Proc. Am. Assoc. Adv. Sci., vol. 39, 1891, pp. 244-245.
6. The Appomattox formation in the Mississippi embayment: Abstract in Bull. Geol. Soc. America, vol. 2, 1891, pp. 2-6.
7. The Lafayette formation: Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1892, pp. 353-521.
8. A fossil earthquake: Abstract in Bull. Geol. Soc. America, vol. 4, 1893, pp. 411-414.

PURDUE, A. H.

1. [Notes on the underground waters of] northern Arkansas: Water-Sup. and Irr. Paper No. 114, U. S. Geol. Survey, 1905, pp. 188-197.

SAFFORD, J. M.

1. A geological reconnaissance of the State of Tennessee; being the author's first biennial report, 164 pp., map. Nashville, 1856.
2. On the Cretaceous and superior formations of western Tennessee: Am. Jour. Sci., 2d ser., vol. 37, 1864, pp. 360-372.
3. Geology of Tennessee. xii, 550 pp., 8 plates, map. Nashville, 1869.
4. Report on the cotton production of the State of Tennessee, with a discussion of its general agricultural features, and a note on cotton production in the State of Kentucky: Tenth Census U. S., vol. 5, 1884, pp. 367-491, map.
5. An annotated catalogue of the mineral springs and wells of Tennessee; a contribution to a report on the water supply of the State: Bull. State Bd. Health (of Tenn.), vol. 1, October, 1885, suppl., pp. 15-16.
6. The economic and agricultural geology of the State of Tennessee; a report on surveys made in west and middle Tennessee, and on the general agricultural geology of the State: Biennial Rept. Comm. of Agr., pp. 55-168, Nashville, 1887.
7. The upland geological formations of Obion, Dyer, Lauderdale, Tipton, and Shelby counties; their general features and sanitary relations: Bull. State Bd. of Health (of Tenn.), vol. 2, 1886, pp. 151-153; vol. 3, 1887, pp. 3-4.
8. Regions in west Tennessee of sulphur waters and chalybeate waters, respectively; the lines of divisions between the two regions; the origin of iron ore: Bull. State Bd. Health (of Tenn.), vol. 4, 1889, pp. 210-212.
9. Report to the general assembly of the State of Tennessee: Senate Jour., pp. 715-739, Nashville 1889. Reports on certain iron ores, clays, and mineral waters of west Tennessee, but deals chiefly with a part of the Tennessee coal field.
10. The water supply of Memphis: Bull. State Bd. Health (of Tenn.), vol. 5, 1890, pp. 98-106; abstract in Proc. Am. Assoc. Adv. Sci., vol. 39, 1891, p. 244.
11. Notes on the Middleton formation of Tennessee, Mississippi, and Alabama: Bull. Geol. Soc. America, vol. 3, 1892, pp. 511-512.

SHEPARD, EDWARD M.

1. The New Madrid earthquake: Jour. Geol., vol. 13, 1905, pp. 45-62.
2. [Notes on the underground waters of] Missouri: Water-Sup. and Irr. Paper No. 114, U. S. Geol. Survey, 1905, pp. 209-219.

WORTHEN, A. H. (director).

1. Geological Survey of Illinois, vol. 1, Geology. xvi, 504, iii, pp., plates, maps. [Springfield], 1866. Contains geology of Pulaski and Massac counties, by Henry Engelmann, pp. 410-455.

INDEX.

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